

# **Best Management Practice Adoption Incentives and Green Insurance: Corn Rootworm IPM Insurance**

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### **Abstract**

Green insurance compensates farmers for losses from best management practice (BMP) failure and, by reducing risk as an impediment to adoption, has been proposed as a policy tool to encourage BMP adoption. A hierarchical model is developed to analyze the impact of green insurance on farmer incentives to adopt an information-based BMP. Analysis focuses on empirical evaluation of corn rootworm integrated pest management (IPM) and IPM insurance. Though not a general result for all green insurance, empirical findings suggest that farmers have little financial incentive to adopt corn rootworm IPM and IPM insurance does little to remedy this situation.

*Key words:* hierarchical model, integrated pest management, Monte Carlo integration, root rating, soil insecticide.

## **Best Management Practice Adoption Incentives and Green Insurance: Corn Rootworm IPM Insurance**

Purchased crop inputs such as fertilizer and pesticides contribute to widespread non-point source pollution problems, including nutrient and chemical contamination of surface and ground water. Alternative production practices, usually called best management practices (BMPs), exist that reduce such pollution by reducing input use through improved efficiency and by using non-polluting substitutes such as information and insurance. Examples include split nitrogen applications, soil nutrient testing, precision agriculture, and integrated pest management. Analyses often show that these and similar BMPs generate cost savings that more than cover BMP costs, yet producers do not readily adopt such practices (Cooper and Keim; Hrubovcak, Vasavada, and Aldy). To encourage adoption of profit-enhancing BMPs such as these, the Farm Security and Rural Investment Act of 2002 reauthorized the Environmental Quality Incentives Program (EQIP) to provide financial incentives (USDA-NRCS).

EQIP follows traditional federal legislation by using subsidies to encourage voluntary adoption. Such programs can be appropriate for BMPs such as terraces, riparian buffer strips and conversion of environmentally sensitive land to non-crop uses, since cost is often the primary impediment to adoption (Wu and Babcock). However, for profit-enhancing BMPs such as those targeted by EQIP, subsidy-based incentive provisions may not be cost effective, because other factors also influence BMP adoption incentives. Analyses and surveys of producers often find risk associated with BMP adoption to be an impediment to adoption (Feather and Cooper; Greene et al.;

Hrubovcak, Vasavada, and Aldy). Nevertheless EQIP focuses only on cost and ignores policy instruments that take advantage of these other pertinent factors.

One policy instrument receiving renewed interest is “green insurance,” a broad term applied to various types of insurance programs associated with environmental concerns (e.g., Edlin; Means; United Nations Environmental Programme; Wernstedt). In this paper, green insurance is single-peril insurance for losses due to BMP failure that is intended to directly address risks associated with BMP adoption in order to reduce their effect as impediments to adoption. As a current example, the Federal Crop Insurance Corporation recently approved a pilot program for nutrient management BMP insurance for 2003 in Iowa, Minnesota, Pennsylvania and Wisconsin (USDA-RMA).

The idea of green insurance is not new. In the 1970’s Turpin proposed insurance to encourage corn rootworm IPM adoption. The Agricultural Conservation Innovation Center (ACIC), in conjunction with IGF Insurance and Iowa Farm Bureau Mutual Insurance Company, has been actively developing BMP insurance policies for private marketing (ACIC). Among these, IGF Insurance developed corn rootworm IPM insurance and filed the policy with insurance regulators in three states (US EPA 1999b). However, the policy has not been actively marketed due to the financial failure of IGF Insurance and subsequent merger with another insurance company.

Previous studies of the impact of insurance and information on producer incentives to reduce input use or adopt input-reducing BMPs have not considered BMP insurance. Miranowski, Ernst and Cummings found that subsidizing information collection costs is superior to yield-based crop insurance for encouraging adoption of IPM among cotton farmers. Chambers and Quiggin use a multi-task principal-agent

model with state-contingent production to derive optimal levels of net insurance indemnities and output for producers generating corn and pollution as joint products. However, they do not focus on adoption of new technology or use of information. Babcock and Hennessy demonstrate that nitrogen fertilizer and crop insurance are substitutes for Iowa corn producers, while Smith and Goodwin show that chemical inputs and crop insurance are substitutes for dryland Kansas wheat producers.

Hennessy and Babcock use second order approximations to derive conditions under which information and inputs are substitutes, but do not address imperfect information, insurance, or risk aversion. Mitchell and Hennessy also use second order approximations to incorporate imperfect information, insurance, and risk aversion and to identify factors other than cost that determine adoption incentives for a BMP utilizing imperfect information to increase input use efficiency. Mitchell shows that empirically, for soil nitrogen testing in corn production, second order approximations perform poorly.

This paper develops a general conceptual model of adoption incentives for an information-based BMP and the impact of green insurance on these incentives. Next the paper empirically applies the model to estimate the value of corn rootworm IPM and to evaluate the impact of corn rootworm IPM insurance on adoption incentives. Because general analytical results have so far remained intractable (e.g., Hennessy and Babcock; Mitchell and Hennessy; Mitchell), a hierarchical model is used for the conceptual and empirical models (Casella and Berger, pp. 162-168). Hierarchical models are convenient, since model specification is intuitive and sampling-based (Monte Carlo) approaches have been developed in Bayesian econometrics to estimate the distribution of hyperparameters

(Gelfand and Smith). These methods are used to estimate conditional and unconditional distributions of farmer utility to determine IPM adoption incentives.

Empirically, we find that the benefits of corn rootworm IPM do not justify the costs, a finding consistent with farmer behavior and some entomological research (Foster et al., Gray and Steffey). We also find that corn rootworm IPM insurance does not significantly increase IPM adoption incentives, so that private provision of corn rootworm IPM insurance as a policy tool to encourage IPM adoption seems unlikely.

### **Conceptual Framework**

The representative producer modeled here manages a homogeneous unit of land normalized to one acre, all devoted to the production of a single crop. All profit is converted to physical output by normalizing the crop price to one. All other income and wealth is ignored. Per acre profit is denoted  $\pi$  and the producer derives utility from this profit according to  $u(\pi)$ , where  $u' > 0$  and  $u'' \leq 0$ . The risk-averse producer maximizes the expected utility of profit, with the profit specification depending on the production system used. For all production systems, a crop growth function  $f(x, \theta)$  transforms a purchased input  $x$  and stochastic input  $\theta$  into per acre crop yield, where  $f_x > 0$  and  $f_{xx} < 0$ .

The input  $\theta$  can be a naturally occurring substitute for  $x$  so that  $f_\theta > 0$  and  $f_{x\theta} < 0$ , as when  $x$  is nitrogen fertilizer and  $\theta$  is nitrogen from natural sources. Alternatively,  $\theta$  can measure the level of a naturally occurring “bad” so that  $f_\theta < 0$  and  $f_{x\theta} > 0$ , as when  $x$  is a pesticide and  $\theta$  measures the pest population. Because natural processes determining  $\theta$  are many and complex, the producer treats  $\theta$  as a stochastic input.

*Status Quo and BMP*

For the status quo, the producer observes that  $\theta$  follows the unconditional density  $v(\theta)$ .

The producer's objective and first order condition are:

$$(1) \quad \text{Max}_x \int_{\theta} u(\pi) v(\theta) d\theta$$

$$(2) \quad \int_{\theta} u'(\pi) (f_x(x, \theta) - p) v(\theta) d\theta = 0$$

where  $\pi = f(x, \theta) - px$  and  $p$  is the per unit price for  $x$  normalized by the output price.

Let  $\tilde{x}$  be the optimal value of  $x$  implicitly defined by the first order condition (assume  $\tilde{x} > 0$ ) and let  $EU_{SQ}$  be the value of the objective function when evaluated at this optimum.

Since  $f_{xx} < 0$  and  $u'' \leq 0$ , the second order condition is satisfied and  $EU_{SQ}$  is a maximum.

For the BMP, the producer first collects imperfect information concerning  $\theta$ , then chooses  $x$ . Let  $\alpha$  denote this signal of the true level of  $\theta$  and let the resulting conditional density of  $\theta$  be  $q(\theta | \alpha)$ . The producer chooses an optimal decision rule  $x^*(\alpha)$  to maximize expected utility for a given  $\alpha$ . The objective and first condition are:

$$(3) \quad \text{Max}_x \int_{\theta} u(\pi) q(\theta | \alpha) d\theta$$

$$(4) \quad \int_{\theta} u'(\pi) (f_x(x, \theta) - p) q(\theta | \alpha) d\theta = 0$$

where  $\pi = f(x, \theta) - px - c$  and  $c$  is the non-random cost of collecting the information  $\alpha$ .

For any  $\alpha$ , the first order condition implicitly defines  $x^*(\alpha)$  (assume  $x^*(\alpha) > 0 \forall \alpha$ ).

Expected utility for this system is the expected value of the objective at  $x^*(\alpha)$ :

$$EU_{BMP} = \int_{\alpha} \int_{\theta} u(\pi(x^*(\alpha))) q(\theta | \alpha) b(\alpha) d\theta d\alpha, \text{ where } b(\alpha) \text{ is the density of } \alpha. \text{ Since}$$

$f_{xx} < 0$  and  $u'' \leq 0$ , the second order condition is satisfied and  $EU_{BMP}$  is a maximum.

The relationship between  $\alpha$  and  $\theta$  is described by the joint probability density  $z(\theta, \alpha)$ , such that  $\alpha$  and  $\theta$  have a positive covariance. The joint density  $z(\theta, \alpha)$  can be factored into the conditional density of  $\theta$  and the unconditional density of  $\alpha$  respectively:  $z(\theta, \alpha) = q(\theta | \alpha) b(\alpha)$ . Also, integrating the joint density over  $\alpha$  gives the unconditional density of  $\theta$ ,  $v(\theta) = \int_{\alpha} z(\theta, \alpha) d\alpha$ .

The information  $\alpha$  provides is imperfect for reasons specific to each BMP, but generic examples include measurement error inherent in the information technology, a time lag occurring between the observation of  $\alpha$  and the realization of  $\theta$ , or spatial variation in the realization of  $\theta$ . Signals of this sort include scouting for insects as part of IPM, which imperfectly estimates pest pressure, and soil testing, which imperfectly estimates soil nutrient availability.

#### *BMP with Green Insurance*

Green insurance compensates producers for losses incurred due to BMP failure. Two types of BMP failures can occur—either too little or too much of the input  $x$  is applied, resulting in profit loss due to reduced yields or wasted expenditures. These failures occur for several reasons. The imperfect nature of  $\alpha$  can mislead the producer, waiting to collect and process  $\alpha$  can result in factors such as inclement weather preventing or delaying application of  $x$ , or the producer may not correctly implement the BMP.

Producers are primarily concerned with input deficiencies and associated yield losses. Input surpluses are usually less costly to producers, since yield loss is minor (if it occurs at all) and typically difficult to detect. Agronomic research has focused on detecting input deficiencies and measuring associated yield losses to develop

recommended application rates. BMP failures that cause input deficiencies are a concern to policy makers as well, since such failures are often observable and create a bad reputation for the BMP. In this analysis, BMP failures that result in over application of the input  $x$  are ignored and the focus is on failures that result in an input deficiency.

The indemnity received is  $I(r, \beta)$ , where  $r$  is a signal, from which expected yield loss due to input deficiency as a result of BMP failure can be inferred, and  $\beta$  is an index of the level of coverage such that  $I_\beta > 0$ . The signal  $r$  is an ex post imperfect signal of input availability that depends on  $x$  and  $\theta$ . Denote its conditional density as  $w(r | x, \theta)$ .

This specification does not explicitly include  $\alpha$ , but because  $x$  depends on the observed  $\alpha$ , the specification depends indirectly on  $\alpha$  and assumes that all dependence of  $r$  on  $\alpha$  is mediated by  $x$ . Signals of this sort already exist for BMPs. Root ratings measure corn rootworm damage for corn rootworm IPM (Spike and Tollefson). The end of season stalk test and SPAD chlorophyll meter readings measure nitrogen deficiency for the late spring soil nitrogen test (Varvel, Schepers, and Francis).

Denote the premium as  $M(\beta)$ , which can be actuarially fair or include a load to cover insurance costs. We treat the level of coverage  $\beta$ , as exogenous to the farmer, since the regulator must choose  $\beta$  not only to balance moral hazard and adverse selection problems and optimal risk sharing, but also to meet policy goals concerning input use.

The producer purchasing insurance chooses an optimal decision rule  $x^*(\alpha, \beta)$  to maximize expected utility conditional on the observed  $\alpha$  and offered  $\beta$ . The objective and first order conditions are:

$$(5) \quad \text{Max}_x \int_{\theta} \int_r u(\pi) w(r | x, \theta) q(\theta | \alpha) dr d\theta$$

$$(6) \quad \int_{\theta} \int_r u'(\pi)(f_x(x, \theta) - p)w(s|x, \theta)q(\theta|\alpha)ds d\theta + \int_{\theta} \int_r u(\pi)w_x(r|x, \theta)q(\theta|\alpha)dr d\theta = 0$$

where  $\pi = f(x, \theta) - px - c + I(r, \beta) - M(\beta)$ . For any  $\alpha$  and  $\beta$  the first order condition implicitly defines  $x^*(\alpha, \beta)$  (assume  $x^*(\alpha, \beta) > 0 \forall \alpha$  and  $\beta$ ). Expected utility is the expected value of the objective function evaluated at  $x^*(\alpha, \beta)$ :  $EU_{GI} = \int_{\alpha} \int_{\theta} \int_r u(\pi(x^*(\alpha, \beta)))w(r|x, \theta)q(\theta|\alpha)b(\alpha)dr d\theta d\alpha$ . Note that  $f_{xx} < 0$  and  $u'' \leq 0$  are no longer sufficient to satisfy the second order condition. As a result, the second order condition is satisfied by assumption to ensure that  $EU_{GI}$  is a maximum.

Solving maximization problems (1), (3), and (5) and calculating  $EU_{SQ}$ ,  $EU_{BMP}$ , and  $EU_{GI}$  is analytically intractable for most realistic model specifications. However, by using a hierarchical model, the conditional and unconditional probability densities of utility and its expected value can be obtained for any empirical specification using sampling-based (Monte Carlo) methods (Gelfand and Smith).

### **Corn Rootworm IPM Insurance**

As a BMP, corn rootworm IPM is consistent with this conceptual model. Many entomologists recommend the use of corn rootworm IPM to reduce unnecessary application of soil insecticides and increase profits, yet farmer adoption remains low. Also, IPM insurance for corn rootworm was proposed as early as 1977, while more recently an actual policy for private marketing has been developed, though active marketing has not occurred (Turpin; US EPA 1999b).

### *General Empirical Model*

Root damage caused by corn rootworm larval feeding reduces plant vigor and yield. Plants with damaged roots are also susceptible to lodging, further reducing plant vigor and yield (Spike and Tollefson). Because hundreds of corn rootworm larvae can infest a single plant and root feeding occurs underground, accurately measuring larval populations is difficult. As a result, entomologists usually assess root damage from larval feeding using a root rating measured in late summer, after larvae have become adults. The root rating is a measure of corn root damage based on the number of corn root nodes exhibiting feeding scars or completely destroyed by larval feeding. The 1 to 6 scale of Hills and Peters is the most widely used, in which 1 indicates no corn rootworm feeding damage and 6 indicates three or more root nodes completely destroyed. Because the root rating is the most common damage assessment measure, it is used as the conditioning variable for determining yield loss and as the signal for determining the indemnity.

Soil insecticide is the input  $x$ , but is a discrete choice for the farmer. Either the farmer does not apply a soil insecticide ( $x = 0$ ) or the farmer applies a soil insecticide at the recommended rate ( $x = 1$ ). For notation,  $r_0$  is the root rating for untreated corn ( $x = 0$ ) and  $r_1$  is the root rating for treated corn ( $x = 1$ ). A stochastic specification is used for the production function:  $f(x, \theta) = y(1 - \lambda(x, \theta))$ , where  $y$  is random pest free yield and  $\lambda$  is proportional yield loss. Yield loss depends directly on the root rating, which depends on both the larval population  $\theta$  and applied soil insecticide  $x$ .

Experimental data from Riedell, Schumacher, and Evenson are used to estimate  $w(r_0 | \theta, x = 0)$ , the distribution of the untreated root rating conditional on the larval population. Experimental data from Gray and Steffey are used to estimate  $w(r_1 | \theta, x = 1)$ ,

the distribution of the treated root rating conditional on the untreated root rating. The same data are used to estimate  $k(\lambda | r)$ , the distribution of proportional yield loss conditional on the root rating, where  $r$  equals  $r_0$  or  $r_1$  and depends on  $\theta$  and  $x$ . The stochastic corn rootworm population model of Mitchell and Riedell is used to estimate  $\nu(\theta)$ , the unconditional distribution of the larval population.

The beta density is used for many of these distributions because it is quite flexible and has upper and lower limits. To develop a conditional density requires specifying the mean and variance as functions of the conditioning variables, then solving for the implied equations for the parameters of the beta density. Often the standard beta density is used, which has upper and lower limits of 0 and 1. Any beta random variable with limits  $b_{lo}$  and  $b_{hi}$  can be rescaled to this standard range by subtracting  $b_{lo}$  and dividing by  $b_{hi} - b_{lo}$ . The standard beta density with parameters  $\nu$  and  $\gamma$  has mean  $m = \nu / (\nu + \gamma)$  and variance  $s^2 = \nu\gamma / [(\nu + \gamma)^2 (\nu + \gamma + 1)]$  (Evans, Hastings, and Peacock). Solving for  $\nu$  and  $\gamma$  gives:

$$(7) \quad \nu = [m^2 (1 - m) / s^2] - m,$$

$$(8) \quad \gamma = [m(1 - m)^2 / s^2] - (1 - m).$$

Substituting equations for the mean and variance into equations (7) and (8) gives the parameters of the standard beta in terms of the conditioning variables.

### *Population Model*

The population model consists of three life stages: eggs ( $e$ ), larvae ( $\theta$ ), and adults ( $\alpha$ ). Larvae hatch in the spring just after corn planting and live in the soil feeding exclusively on corn roots, which causes yield loss. In mid-summer larvae pupate in the soil and emerge as adults. In the soil of corn fields, adult females lay eggs that emerge as next year's adults. Because effectively applying soil insecticides to corn roots when larvae are

present is difficult, the standard treatment when planting corn following corn is to apply a soil insecticide in the furrow at plant, before eggs hatch. Corn rootworm IPM involves counting the number of adults in late summer, then applying a soil insecticide the next spring at plant only if the count exceeds the threshold.

Obtaining the necessary data to develop a stochastic population model that links these key life stages is difficult. As a result, the corn rootworm population model of Mitchell and Riedell is adapted. Parameterizing their model for Boone County, Iowa, 10,000 years of simulated corn rootworm populations for each life stage were generated and used to estimate the following stochastic relationships between the three life stages.

The initial larval population is  $\theta = \eta e$ , where  $\eta$ , the proportion of eggs laid the previous year that remain viable through the winter and hatch, is a normal random variable with mean 0.6 and standard deviation 0.08. The adult population is  $\alpha = s\theta$ , where  $s$ , the proportion of larvae that survive to emerge as adults, is a standard beta random variable with parameters  $\nu = 2.923$  and  $\gamma = 21.45 + 0.0304\theta$ . The total number of eggs laid,  $e$ , is a gamma random variable with mean  $45.53\alpha$  and standard deviation  $7.246\alpha^{0.977}$ , implying a scale parameter  $1.153\alpha^{0.954}$  and shape parameter  $39.48\alpha^{0.046}$ . All parameter estimates have p values  $< 0.001$ , so that the population mean and variance for each life stage closely match those of the full model.

#### *Untreated Root Rating*

Three years of data from artificial infestation experiments were used to estimate the distribution of the root rating conditional on the larval population. The data included 216 observations of the untreated root rating  $r_0$  and the larval population  $\theta$ . See Riedell, Schumacher, and Evenson for a complete description of the experiments and data.

Since the root rating is an index between 1 and 6, we assume a beta distribution for  $w(r_0 | \theta, x = 0)$ . Non-concavity of the likelihood function precluded maximum likelihood estimation (Nelson and Preckel), so the method of moments was used to estimate the conditional density. For the conditional density, functions for the mean and standard deviation conditional on the initial larval population were developed, then the implied parameters for the beta density calculated.

A negative exponential model was used for the mean so that  $r_0$  began at 1 and asymptotically approached the maximum of 6:  $m_r = 1 + 5(1 - \exp(-\phi\theta))$ . The model was transformed to  $\ln((6 - m_r) / 5) = -\phi\theta$ , then the observed  $r_0$  were substituted for  $m_r$  and least squares regression used to estimate  $\phi = 0.000457$ . Thus, the conditional mean of the untreated root rating is  $m_r = 6 - 5 \exp(-0.000457\theta)$ .

Because the experiment used only four population levels,  $s_r$ , the standard deviation of the untreated root rating conditional on initial larvae, was fit as a quadratic spline to the four observed standard deviations at each population level. Table 1 reports the coefficients. The standard deviation begins near zero, quickly increases to almost reach one at about 1200 larvae, gradually falls to 0.805 by about 2100 larvae, then remains at this level as the larval population increases. Given the larval population, the conditional mean and standard deviation of  $r_0$  can be calculated, then equations (7) and (8) used to determine the parameters  $\nu$  and  $\gamma$ .

### *Root Rating Difference*

Three years of data from experiments conducted near Urbana, Illinois were used to estimate the conditional distribution of the decrease in the root rating when a soil insecticide is applied. See Gray and Steffey for a complete description of the data and

experiments. The final data set included 330 observations of the untreated yield ( $y_0$ ) and root rating ( $r_0$ ) and the treated yield ( $y_1$ ) and root rating ( $r_1$ ). Proportional yield loss is  $\lambda = (y_1 - y_0) / y_1$  and the root rating difference is  $d = r_0 - r_1$ .

These data were used to estimate the distribution of the root rating difference conditional on the untreated root rating. The root rating difference has upper and lower limits. The minimum of zero occurs when the two root ratings are equal, assuming the untreated root rating equals or exceeds the treated root rating (the data do not violate this assumption). The maximum root rating difference is  $r_0 - 1$ . Given the upper and lower bounds, a conditional beta distribution is estimated with limits 0 and  $r_0 - 1$ .

For the conditional mean, a zero intercept was imposed so the expected root rating difference is zero when the untreated root rating indicates no corn rootworm damage. Scaling the data to the standard beta density range of 0 to 1 indicated that a quadratic mean was appropriate. However, scaling the conditional mean and standard deviation back to the unscaled range of 0 to  $r_0 - 1$  requires multiplying by  $r_0 - 1$ , so that the quadratic mean becomes a cubic function. The specific model estimated for the mean was  $m_d(r_0) = d_1(r_0 - 1)^2 + d_2(r_0 - 1)^3$ , where  $d_1$  and  $d_2$  are parameters. Using this equation for  $m_d$  and assuming a constant standard deviation  $s_d$ , equations (7) and (8) can be used to specify the likelihood function in terms of  $r_0$  and the parameters  $d_1$ ,  $d_2$  and  $s_d$ . Maximum likelihood estimates, with standard errors in parentheses, are  $d_1 = 0.321$  (0.00872),  $d_2 = -0.0379$  (0.00212), and  $s_d = 0.0934$  (0.00348).

### *Proportional Yield Loss*

The Gray and Steffey data were also used to estimate the distribution of proportional yield loss conditional on the root rating difference. Plots indicated an approximately

linear relation between proportional yield loss and the root rating difference, with substantial variation in yield loss for a given root rating difference. This variation results from the many random environmental factors that influence yield loss. In some instances, these factors overwhelm the treatment effect of the soil insecticide and negative losses result, i.e. the treated yield is less than the untreated yield, even though the treated root rating is less than the untreated root rating. The estimated model preserves these properties of the data.

For estimation, a zero intercept was imposed so that mean loss is zero when root ratings do not differ. Maximum likelihood estimates for the model  $\lambda = b_\lambda d + s_\varepsilon \varepsilon$ , where  $\varepsilon \sim N(0,1)$ , are  $b_\lambda = 0.128$  (0.00406) and  $s_\varepsilon = 0.191$ (0.00745), with standard errors in parentheses. Since the normal error has support from negative to positive infinity, some non-zero probability exists with this model that  $\lambda$  exceeds 100%. At the maximum possible root rating difference of 5.0, this probability is slightly more than 3%.

Proportional yield loss for soil insecticide treated corn follows a normal distribution with mean  $b_\lambda(r_0 - r_1)$  and standard deviation  $s_\varepsilon$ . For untreated corn, proportional yield loss also follows a normal distribution, with mean  $b_\lambda(r_0 - 1)$  and standard deviation  $s_\varepsilon$ . Thus mean loss for treated corn is always less than for untreated corn, but the  $\varepsilon$  error implies that the realized yield loss may be greater for the treated corn than for the untreated corn, just as the data indicated occurred for some replicates.

### *IPM Model*

In the context of this model, IPM requires observing the adult population  $\alpha$ , then

applying insecticide if it is above the threshold  $\alpha_T$ , so that  $x^*(\alpha) = \begin{cases} 0 & \text{if } \alpha < \alpha_T \\ 1 & \text{if } \alpha \geq \alpha_T \end{cases}$ . To

aid interpretation and because soil insecticides have different recommended application rates,  $x^*(\alpha)$  is converted to the proportion of years that soil insecticide is applied. The optimal status quo rate is  $\tilde{x} = 1.0$  because the status quo practice is to apply soil insecticide every year. The IPM optimum is some proportion  $\leq 1.0$  because each field is generally not treated every year when IPM is used.

As long as damage increases in the larval population,  $\theta$  is an input with a negative marginal product ( $f_\theta < 0$ ). Because the marginal yield increase from applying soil insecticide increases as the larval population increases—high larval populations imply an increased frequency of insecticide application— $x$  and  $\theta$  are complementary inputs ( $f_{x\theta} > 0$ ). To adjust the larval population model for insecticide use, insecticide reduces initial larval populations by 60% so that  $\theta = \eta e(1 - 0.60x)$ . Sensitivity analysis indicates that conclusions are robust to the insecticide efficacy assumption.

All other random factors contributing to corn yield are aggregated into pest free yield  $y$ . For this analysis, pest free yield follows a beta density with minimum of zero and maximum of 212 bu/ac, and parameters  $\nu = 3.26$  and  $\gamma = 1.61$ . These parameters, imply a mean yield of 141.9 bu/ac and a standard deviation of 41.2, which are consistent with Boone County, Iowa yields. Pest free yield is independent of the corn rootworm population ( $\theta$  and  $\alpha$ ).

For more intuitive results presentation, economic variables are no longer normalized by the corn price and a non-random cost of production is included in per acre returns calculations. We use \$2.00/bu for the corn price and \$200/ac for the cost of production. With these assumptions, profit (\$/ac)  $\pi = 2f(x, \theta) - px - 200$ , where

$f(x, \theta) = y(1 - \lambda(x, \theta))$  is harvested corn yield,  $\lambda(x, \theta)$  represents proportional yield loss as it depends on  $r_0$  and  $r_1$ , which depend ultimately on  $x$  and  $\theta$ , and  $p$  is the cost of an insecticide treatment, which typically ranges \$12-15/ac. For the status quo  $x = 1$ , while for IPM  $x = 0$  or 1 depending on the realized level of  $\alpha$ .

To include risk preferences in the analysis requires specifying a utility function. To avoid wealth effects, we assume constant absolute risk aversion (CARA), so that  $u(\pi) = 1 - \exp(-\rho\pi)$ , where  $\rho$  is the coefficient of absolute risk aversion. Following the method of Babcock, Choi, and Feinerman, reported results use  $\rho = 0.00429$  and  $0.00940$ , which are consistent with a risk premium of 20% and 40% of the standard deviation of profit and indicative of a moderately risk averse and a highly risk averse producer respectively. Sensitivity analysis indicates the robustness of results to this assumption.

Analytically deriving the conditional distribution of utility to solve maximization problems (1) and (3) is intractable for the specified model. However, Monte Carlo methods can be used to derive the conditional and unconditional distribution of utility and its expected value (Gelfand and Smith). Monte Carlo integration is combined with a grid search to calculate expected utility and find the optimal threshold  $\alpha_T$ . Inverting the utility function gives certainty equivalents (\$/ac) for each expected utility and the difference between certainty equivalents with and without IPM measures adoption incentives. The profit specification does not include adoption costs  $c$ , but with a CARA utility function, adoption incentives can be directly compared to IPM cost estimates.

Monte Carlo integration involved initializing the population model with 1,000 eggs and drawing random variables sequentially from larvae to adults to eggs for 200,000 observations. Insecticide use was determined for IPM scenarios using observed adults  $\alpha$

and threshold  $\alpha_T$ . The grid search for  $\alpha_T$  was between 0 and 49 adults per square meter with step size of 0.25, equivalent to 0 to 7 adults per plant, with a step size of 0.0357. For each resulting larval population  $\theta$ , first the untreated root rating is drawn, then the root rating difference is drawn, then proportional yield loss for both treated and untreated corn. For IPM, if soil insecticide is applied, then the treated loss is used to calculate profit, otherwise the untreated loss.

### *IPM Insurance Model*

For the producer with IPM insurance  $\pi = 2f(x, \theta) - px - 200 + I(r_0, D) - M(D)$ , where  $x$  is  $x^*(\alpha, D)$ ,  $I(r_0, D)$  is the indemnity,  $M(D)$  is the premium, and  $D$  is the deductible.

The indemnity equals the expected yield loss conditional on the untreated root rating, minus the deductible:  $I(r_0, D) = \text{Max}\{0, E[y](1 - E[\lambda | r_0]) - D\}$ , where  $E[y]$  is expected pest free yield and  $E[\lambda | r_0]$  is expected yield loss given the untreated root rating. To be consistent with the general theoretical model,  $\beta = -D$  and the insurance signal  $r$  is the untreated root rating  $r_0$ . Simplifying the indemnity using relationships described in the damage model gives  $I(r_0, D) = \text{Max}\{0, 0.128(r_0 - 1) - D\}$ .

The actuarially fair premium  $M(D) = E[I(r_0, D)]$  is a useful benchmark for insurance evaluation. Determining the fair premium requires solving  $M(D) =$

$$\int_0^\infty \int_0^6 \int_0^1 I(r_0, D) w(r | \theta, x^*(\alpha, D)) q(\theta | \alpha) b(\alpha) dr d\theta d\alpha$$

, since the untreated root rating is conditional on the population. However, since no closed form for  $b(\alpha)$  exists for the specified population model, the fair premium is determined numerically using Monte Carlo integration by drawing adults  $\alpha$  and larvae  $\theta$  sequentially from the population

model. As for the IPM model, the analysis uses the CARA utility function to include risk preferences and solves optimization problem (5) using Monte Carlo integration and a grid search to determine the optimal threshold  $\alpha_T$ .

## **Empirical Results**

### *Optimal Application Rate*

A grid search identified the optimal IPM adult threshold  $\alpha_T$  for each production system.

Figure 1 illustrates a typical curve for the relationship between  $\alpha_T$  and expected profit.

The status quo practice occurs at  $\alpha_T = 0$ , while the expected profit maximizing  $\alpha_T$  occurs at some  $\alpha_T \geq 0$ . Expected profit first increases slightly as  $\alpha_T$  increases, but in general is fairly flat until it begins to fall rapidly at higher values for  $\alpha_T$ . For risk-averse farmers, the plot of certainty equivalents versus the threshold  $\alpha_T$  has the same essential shape, but a different optimal  $\alpha_T$ . Over a wide range of parameter values, the expected profit maximizing  $\alpha_T$  ranged between 0.5 and 2.5 adults/plant, with most falling between 0.75 and 2.0 adults/plant. These values are consistent with the thresholds recommended by entomologists, which typically range 0.75 to 1.0 adults/plant (Foster et al.; Stamm et al.).

The threshold  $\alpha_T$  implies an application rate  $x^*(\alpha_T)$  and  $x^*(\alpha_T, D)$ , which here has been normalized to a percentage between 0% (never apply) and 100% (always apply). This application rate is the average percentage of acres treated or the average probability that a field will be treated. Figure 2 plots the percentage of acres treated when using the optimal  $\alpha_T$  versus the insecticide price as an example of typical demand curves for each production system. The application rates with IPM are still quite high—in excess of 90% of acres will be treated when adopting IPM. This result is consistent with the finding of

Foster et al., who with a sample of about 40 fields over three years in Iowa report an application rate of 95% for farmers using corn rootworm IPM.

Figure 2 indicates that risk aversion decreases the optimal application rate, a result consistent with other conceptual and empirical analyses for corn rootworm and other pests (Horowitz and Lichtenberg; Lazarus and Swanson; Pannell). These analyses show that pest control does not necessarily reduce yield variance. As a result, pest control inputs can be risk increasing so that risk averse farmers use less than risk neutral farmers. Our finding is similar to this result, since IPM adoption and IPM insurance coverage only minimally reduces the standard deviation of per acre profit. Over a wide range of insecticide prices, insecticide efficacies, levels of risk aversion, and insurance deductibles, adopting IPM with or without IPM insurance reduces the standard deviation of per acre profit less than 1%.

#### *Value of Corn Rootworm IPM*

For a risk neutral farmer, the value of IPM is the difference in status quo expected profit at  $\alpha_T = 0$  and expected profit at the optimal  $\alpha_T$ . For a risk averse farmer, the value is the difference between certainty equivalents at  $\alpha_T = 0$  and the optimum. Table 2 summarizes results for the value of IPM for a variety of insecticide costs and levels of risk aversion. The values are quite small and insufficient to justify the cost of scouting for adults.

The general shape of the plot in Figure 1 remains essentially the same for a wide range of parameter values. Since the curve in Figure 1 is fairly flat between  $\alpha_T = 0$  and the optimum, the value of IPM for risk neutral and risk averse farmers is quite small. This is largely due to the small reduction in the average pesticide application rate when

adopting IPM—the savings in reduced insecticide applications are not that significant. As a result, farmers have little economic incentive to adopt corn rootworm IPM.

The entomological literature is mixed on the economic value of corn rootworm IPM to farmers. Using three years of field data from Nebraska, Stamm et al. find that IPM generates sufficient saving to justify the cost of scouting. Foster et al. use three years of field data in Iowa to find the opposite conclusion, which is consistent with our findings for a typical field in central Iowa. The fairly flat shape of the curve between  $\alpha_T = 0$  and  $\alpha_T = 3$  (well above the optimal  $\alpha_T$ ) in Figure 1 indicates a possible reason for the mixed results in entomological studies using field data. The curve represents the average of 200,000 random draws, but the entomological results are derived from small samples ( $< 120$ ), so that the many sources of uncertainty can lead to mixed results. If two small Monte Carlo samples were compared, similar mixed results could easily occur.

#### *Corn Rootworm IPM Insurance*

Figure 3 illustrates the actuarially fair premium for corn rootworm IPM insurance as the treatment threshold increases. The fair premium is generally linear in  $\alpha_T$ , with the slope depending on the deductible. For all reported results, the fair premium associated with the optimal  $\alpha_T$  is used. Therefore, since the optimal  $\alpha_T$  depends on the level of risk aversion and the insecticide cost, the premium does as well. Table 3 reports fair premiums for a variety of insecticide costs and two levels of risk aversion. In addition, to give some indication of the frequency of insurable losses, the probability of receiving an indemnity is reported as well. These premiums are slightly less than the comparable premiums developed by IGF Insurance for corn rootworm IPM insurance. However, the

premiums in Table 3 are fair premiums and so, unlike commercial premiums, do not include a premium load to cover administrative and overhead costs of the insurance.

Table 3 also reports the willingness to pay for IPM insurance with a fair premium, or equivalently, the impact of IPM insurance with a fair premium on IPM adoption incentives. The impact is quite small and unlikely to generate a substantial increase in adoption among farmers. Furthermore, since fair premiums do not include a load to cover administrative and other insurance costs, and because the analysis assumes CARA preferences, this willingness to pay would decrease by the amount of the load once it is added. As a result, since the willingness to pay is quite small, a viable private market for corn rootworm IPM seems unlikely.

The reported willingness to pay for corn rootworm IPM in Table 2 and for corn rootworm IPM insurance in Table 3 do not include two important costs. No cost for adopting IPM is included (i.e., the cost of scouting to measure the number of adults per plant) and no premium load to cover administrative and other insurance costs. Even without these costs, the incentives to adopt IPM or to purchase IPM insurance are quite small. As a result, IPM insurance would encourage IPM adoption only if a premium subsidy were included to cover these costs. A premium subsidy of this magnitude is currently available for federal crop insurance policies in order to meet the legislated participation goals of the Agricultural Risk Protection Act (ARPA) of 2000. Not only are the administrative and overhead costs subsidized, but part of the fair premium is as well. However, this analysis, like that of Foster et al., finds that IPM adoption only minimally reduces the use of soil insecticides, so that a subsidy program is not likely to meet the ultimate ARPA policy goal of lower insecticide use.

Extensive sensitivity analysis was conducted for this analysis. Insecticide efficacy was varied from 50% to 70%, the insecticide cost from \$6/ac to \$18/ac, the deductible from 0% to 7%, and risk aversion from an implied risk premium that was as high as 40% of the profit standard deviation. The results of this analysis are not reported, but in no case did the qualitative results change. Corn rootworm IPM did not generate a sufficient increase in expected profit or certainty equivalents to justify the cost of scouting for adults, nor did corn rootworm IPM insurance sufficiently increase certainty equivalents to justify the administrative and overhead cost of the insurance. As a result, we conclude that the financial gain from adopting corn rootworm IPM is not likely to justify the adoption costs. Similarly, we conclude that corn rootworm IPM insurance is not likely to substantially increase IPM adoption incentives for most farmers, nor is private marketing of corn rootworm IPM insurance likely.

Several caveats apply to our conclusions, foremost being the reliance on a population model instead of field data to determine corn rootworm population pressure. However, though we use a different method, we reach the same conclusion as Foster et al. concerning the value of corn rootworm IPM to farmers. Also, our results do not apply to other types of corn rootworm IPM, such as methods based on adult counts from traps. A better method of evaluating corn rootworm IPM insurance would be to collect and analyze long-term field data, but obtaining such data is time-consuming and expensive.

### **Conclusion**

Green insurance is a broad term referring to a variety of insurance programs using insurance to mitigate environmental problems (Edlin; Means; United Nations Environmental Programme; Wernstedt). In agricultural contexts, green insurance has

focused primarily on best management practice (BMP) insurance to encourage adoption of practices that improve the environmental performance of agricultural crop production. For example, the Federal Crop Insurance Corporation recently approved a pilot program for nutrient management BMP insurance and the Agricultural Conservation Innovation Center has worked with crop insurance companies to develop several BMP insurance policies for private marketing (ACIC; USDA-RMA; US EPA 1999b).

This paper developed a conceptual, hierarchical model of green insurance for an information-based BMP and illustrated how to use Monte Carlo methods to evaluate proposed insurance products as policy tools to encourage BMP adoption. Unfortunately, empirical analysis of corn rootworm IPM insurance found little impact of the insurance on adoption incentives, primarily because the insurance did not significantly reduce the variance of per acre returns. The minor impact on yield variance from reducing pest damages has been demonstrated conceptually and empirically (Horowitz and Lichtenberg; Pannell). Our results are consistent with these findings and imply that IPM insurance may not be a fruitful place to search for green insurance products.

Besides the previously mentioned caveats for our empirical results, it is important to note that our results do not apply generally to all green insurance policies, but to a specific information-based BMP and insurance against input deficiency resulting from the imperfect nature of the information. BMP insurance for other types of practices with different sources of risk may have different results. Lastly, these results imply that current programs such as EQIP that encourage adoption of practices such as IPM, rightly focus on cost sharing rather than risk sharing.

Table 1. Spline Coefficients for Root Rating Standard Deviation Conditional on the Initial Larval Population.

Coefficient	----- Initial Larval Population -----		
	< 1700	1700 – 2115	> 2115
Constant	$5.781 \times 10^{-2}$	$1.389 \times 10^0$	$8.050 \times 10^{-1}$
Linear	$1.451 \times 10^{-3}$	$-4.138 \times 10^{-4}$	0
Quadratic	$-5.713 \times 10^{-7}$	$6.503 \times 10^{-8}$	0

Table 2. Expected profit ( $E[\pi]$ ), certainty equivalent (CE), and willingness to pay (WTP) for corn rootworm IPM for a variety of insecticide costs and risk aversion levels.

	----- Insecticide Cost (\$/ac) -----					
	8.00	10.00	12.00	14.00	16.00	18.00
<b>Risk Neutral</b>						
Status Quo $E[\pi]$	33.52	31.72	29.74	27.65	25.73	23.65
IPM $E[\pi]$	33.53	31.75	29.80	27.75	25.91	23.94
WTP for IPM	0.01	0.03	0.05	0.11	0.18	0.29
<b>20% Risk Premium</b>						
Status Quo CE	23.61	21.81	19.82	17.75	15.83	13.74
IPM CE	23.62	21.84	19.88	17.86	16.01	14.03
WTP for IPM	0.01	0.03	0.06	0.11	0.18	0.29
<b>40% Risk Premium</b>						
Status Quo CE	12.54	10.45	8.46	6.27	4.38	2.27
IPM CE	12.55	10.48	8.52	6.38	4.58	2.58
WTP for IPM	0.01	0.03	0.06	0.11	0.20	0.31

Table 3. Fair premiums, probability of receiving an indemnity, certainty equivalent (CE), and willingness to pay (WTP) for corn rootworm IPM insurance for a variety of insecticide costs and two risk aversion levels.

	----- Insecticide Cost (\$/ac) -----					
	8.00	10.00	12.00	14.00	16.00	18.00
<b>20% Risk Premium</b>						
Fair Premium	1.51	3.15	4.96	7.06	9.36	10.60
Pr[Indemnity > 0]	0.1%	0.4%	0.9%	1.9%	3.1%	4.0%
IPM Insurance CE	23.62	21.84	19.88	17.87	16.02	14.05
WTP for Insurance	0.00	0.00	0.00	0.01	0.01	0.02
<b>40% Risk Premium</b>						
Fair Premium	2.19	3.96	6.12	7.75	10.72	13.39
Pr[Indemnity > 0]	0.2%	0.6%	1.4%	2.2%	4.2%	6.3%
IPM Insurance CE	12.55	10.48	8.53	6.39	4.61	2.64
WTP for Insurance	0.00	0.00	0.01	0.01	0.03	0.05



Figure 1. Plot of expected profit versus the IPM treatment threshold  $\alpha_T$  (14 \$/ac insecticide cost, 60% insecticide efficacy).

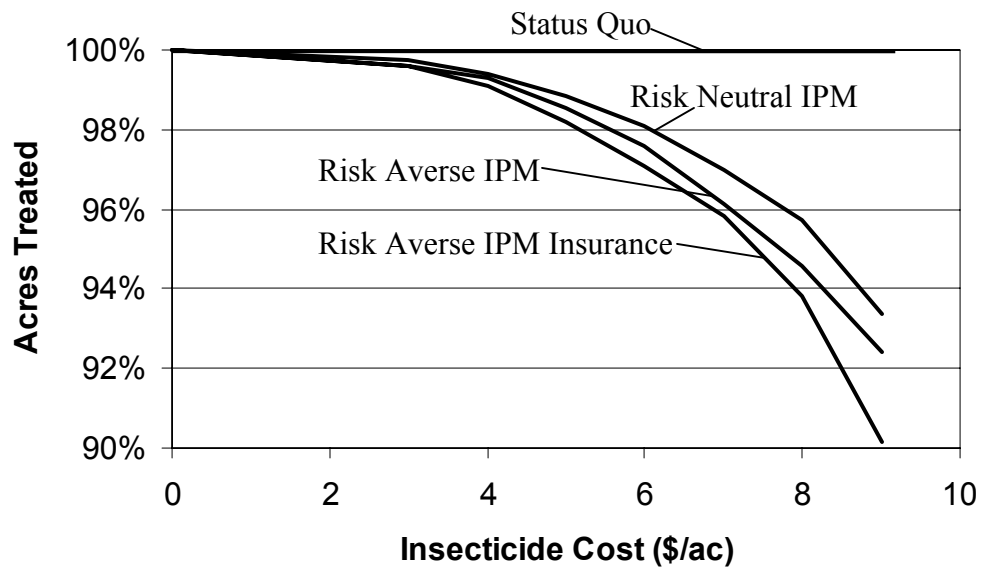


Figure 2. Impact of risk aversion and corn rootworm IPM insurance on optimal demand for soil insecticide (40% risk premium, 7% deductible, 60% insecticide efficacy).

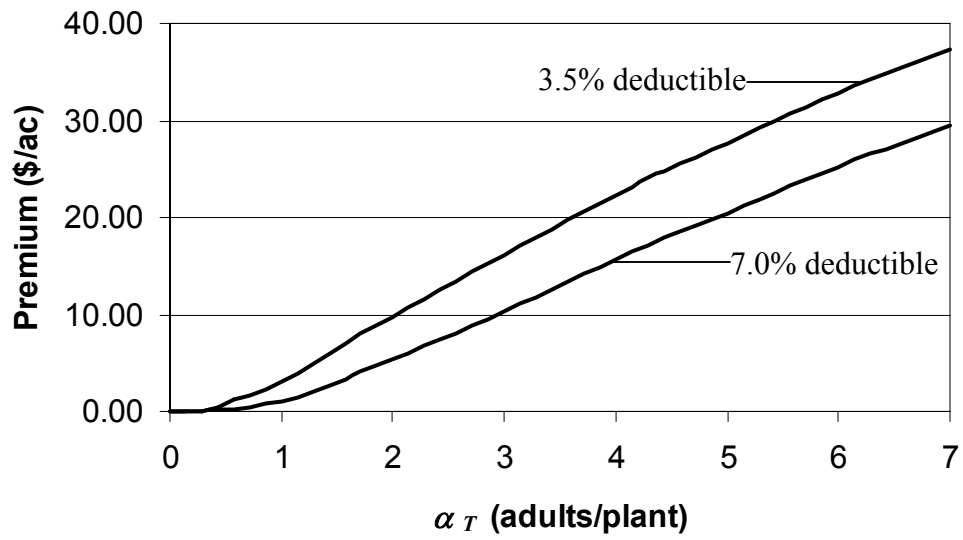


Figure 3. Plot of the actuarially fair corn rootworm IPM insurance premium versus the IPM treatment threshold  $\alpha_T$  (14 \$/ac insecticide price, 60% insecticide efficacy).

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