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Estimating the Benefits of Bt Corn and Cost of Insect Resistance Management Ex Ante

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This paper estimates farmer benefits for corn rootworm (CRW) active Bt corn and costs of complying with Environmental Protection Agency insect resistance management requirements. The estimates are obtained from farmer survey data that were collected in Minnesota in 2002, just prior to the commercial release of CRW Bt corn. Benefit estimates range from \$14 to \$33.4 million, while compliance cost estimates range from \$3.5 to \$8.7 million depending on whether or not CRW Bt corn also controlled the European corn borer and whether or not it was approved for sale in major export markets.

Key words: Bt corn, compliance costs, corn rootworm, insect resistance management, willingness to pay

Introduction

Bt corn contains genes from the soil bacterium *Bacillus thuringiensis*. These genes instruct the plants to produce proteins that are toxic to specific insect pests. The first varieties of Bt corn, commercially released in 1996, primarily controlled European corn borer (ECB). In 2003, the U.S. Environmental Protection Agency (EPA) approved Monsanto's corn rootworm (CRW) Bt corn for commercial release. This was followed by the approval and release of Monsanto's CRW and ECB Bt corn in 2004, and Mycogen and Pioneer's CRW Bt corn in 2005.

Annual yield loss and control costs attributed to three different species of CRW (Northern, Southern, and Western) have been estimated to exceed \$1 billion (Metcalf, 1986), making it one of the most important corn insect pests in the United States. Insecticide treatments for CRW have been relatively common. For example, in 1996, more than 60% of insecticide treatments on corn targeted CRW, which make it the most commonly treated corn insect pest (Fernandez-Cornejo and Jans, 1999). In addition to using insecticide for CRW control, many farmers rotate corn with soybeans (i.e., 67% of corn acres) (Payne, Fernandez-Cornejo, and Daberkow, 2003). While insecticide treatments and crop rotation have been effective methods for CRW control, insecticide resistance has been documented in Western CRW populations (Meinke et al., 1998), and rotation resistance has been documented in Northern and Western CRW populations

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(Payne, Fernandez-Cornejo, and Daberkow, 2003). As resistant populations of the Northern and Western CRW spread, new control strategies like CRW active Bt corn become more important to farmers. In 2005, 33% of U.S. corn acreage was planted with Bt corn, which reflects a 37.5% increase in adoption since the introduction of CRW active Bt corn [U.S. Department of Agriculture/National Agricultural Statistics Service (USDA/NASS), 2005].

Widespread adoption of Bt corn also carries the risk of resistance—a risk that poses an obstacle to sustainability (Alstad and Andow, 1995). Even though Bt corn resistance has not yet been documented in the field, ample empirical evidence suggests the threat is real [see U.S. EPA (1998) for a review]. The EPA requires farmers to follow insect resistance management (IRM) plans due to the threat of resistance. In a 1998 white paper, the EPA (p. 1) expresses the agency's objectives for these plans: "Pesticide resistance management is likely to benefit the American public by reducing the total pesticide burden on the environment, and by reducing the overall human and environmental exposure to pesticides." That paper also illuminates the tradeoffs and constraints of concern to the EPA: "It is the desire of the EPA that this focus on pesticide resistance management not overly burden the regulated community, jeopardize the registration of reduced risk pesticides, or exclude conventional pesticides or other control practices which can contribute to the further adoption of integrated pest management (IPM)."

The EPA's IRM requirements were formulated and continue to be revised in an active environment of agency, industry, and academic debate. The requirements obligate farmers to plant a structured refuge with conventional corn. The requirements specify the size of the refuge, the location or configuration of refuge in relation to Bt corn, and the availability of the option to use non-Bt insecticide treatments on refuge for supplemental control. A structured refuge promotes the sustainability of Bt corn by providing habitat for Bt-susceptible insects and encouraging random mating with Bt-resistant insects. With a structured refuge, most insect progeny will be susceptible to Bt, so resistance evolves slower.

Simulation models have played a key role in helping the EPA decide how much refuge should be required, where it should be planted, and when it should be treated for supplemental control (e.g., Alstad and Andow, 1995; Roush and Osmond, 1996; Gould, 1998; Onstad and Gould, 1998). These models are biologically detailed, but lack socioeconomic detail. In particular, the models assume full adoption of Bt corn and full compliance with IRM requirements. USDA data reveal a lack of full adoption, while the Agricultural Biotechnology Stewardship Technical Committee (ABSTC, 2005), Jaffe (2003), and Goldberger, Merrill, and Hurley (2005) show a lack of full compliance. The potential for partial adoption and compliance to undermine the success of the EPA's IRM program is illustrated by Hurley (2005). Partial adoption of Bt corn makes resistance less likely, so existing requirements may be too strict. Alternatively, partial compliance makes resistance more likely, so existing requirements may not be strict enough. Hurley provides only a cautionary tale, however, because of the lack of information required to accurately characterize the relationship between the EPA's IRM policy and farmer adoption and compliance behavior.

Accordingly, the purpose of this study is to explore the potential for using the contingent valuation (CV) method to help fill this informational gap. To accomplish this objective, Minnesota farmers were surveyed and asked if they would plant a variety of

Bt corn with certain characteristics if it were available. Specifically, the Bt varieties that were described to farmers varied by spectrum of control, export market approval, IRM requirements, and price. Using a probit model, the distribution of farmers' willingness to pay (WTP) for Bt corn can be characterized in terms of these factors. This WTP distribution can then be used to estimate adoption, welfare benefits, and IRM compliance costs for Bt corn.

Materials and Methods

Survey Sample

The survey was conducted between April and June 2002, following procedures outlined by Dillman (2000). The survey was mailed to 2,000 Minnesota corn farmers who produce more than $1,000 worth of farm commodities. The sample was randomly and confidentially drawn from the Minnesota Agricultural Statistics Service's database. The initial response rate was about 45%. After eliminating respondents who were no longer farming, explicitly refused to complete the survey, or did not complete the relevant portions of the survey, 630 responses (31.5%) remained.

Survey Design

The survey consisted of four sections.[1] First, general information about the farm was queried (e.g., farm size, crops planted, and livestock produced). The next section asked about the farmer's experience with insect management and knowledge about Bt corn regulations. The third section is the most relevant for this research and is described further below. It focused on eliciting the value of a new Bt corn pest management program. The concluding section asked for demographic information (e.g., age, education, and off-farm work).

The third section of the survey set up and asked a referendum CV question (see the appendix). The CV method is widely used to elicit preferences for nonmarket goods by asking people their willingness to pay. It circumvents the absence of markets by presenting a hypothetical market in which people can buy the good (Mitchell and Carson, 1989, pp. 2–3). The design of this survey follows the same principle. While Bt corn is a private, not public, good, a hypothetical market was used because the hybrids of interest had not been approved for commercial sale at the time of the survey.

The hybrids proposed for sale varied in terms of their spectrum of control, export market approval, IRM requirements, and price. A detailed description of how the survey varied randomly for each farmer along these dimensions is provided in Langrock and Hurley (forthcoming), so only a general overview and motivation are given here.

Four distinct spectrums of control were considered. All hybrids were described as controlling CRW populations and damage to corn. Some were identified as providing 95% CRW population control, while others were described as providing 75% control. Both were described as providing 95% damage control. In addition to providing CRW control, some were characterized as providing 95% population and damage control for ECB. Whether the hybrid controlled CRW, or CRW and ECB, was varied to explore

[1] A copy of the survey is available from the authors on request.

obvious scope effects. All else equal, a hybrid that controls ECB in addition to CRW should be at least as valuable. It was also varied because both types of hybrids were headed for commercialization at the time of the survey. The efficacy of CRW population control was varied because at the time of the survey, companies were developing products with varying levels of CRW population control. Clark and Carlson (1990) found that farmers may be unwilling to pay for population control with mobile pests because it is a public benefit. Because adult CRW beetles are mobile, positive or negligible population control benefits were expected.

Whether the produce of Bt corn was approved for sale in major export markets was varied to investigate the importance of export market access. Export market access was expected to increase the willingness to pay, but only if a farmer typically sells to these markets. The practical importance of this distinction continues because not all Bt corn hybrids are approved for sale in markets such as Europe and Japan.

The survey varied in terms of whether or not farmers would be subject to IRM requirements. If they were subject to requirements, the types of requirements varied according to the refuge size, configuration, and option to treat with non-Bt insecticides. The alternative minimum refuge sizes included 10%, 20%, 30%, 40%, and 50%. At the time of the survey, 20% was required for ECB Bt corn in the Midwest, but some entomologists recommended 50% for CRW Bt corn (U.S. EPA, 2002). The alternative configurations included nine combinations of four configurations that were either being allowed by or proposed to the EPA at the time of the survey: Bt and non-Bt seed mixes, multiple within-field refuge strips, within-field refuge blocks, and separate refuge fields. The 9 out of 15 possible combinations used in the survey were chosen to be consistent with alternative biological objectives based on insect mobility and mating behavior. While the EPA allowed refuge treatments at the time of the survey (and still does), treatments may be restricted in the future if research shows they hinder IRM success.

The proposed additional cost of Bt seed corn (i.e., the price premium) varied from \$5 to \$40 per acre of Bt corn in \$1 increments. This cost was described as representing how much more the farmer would be willing to pay relative to conventional varieties that differed only due to their lack of the Bt genes. At the time of the survey, ECB Bt corn was selling for \$8 to \$10 an acre with adoption rates in Minnesota around 30%. Therefore, a product with both CRW and ECB activity could sell for more than \$10 an acre. However, with crop rotation as a substitute for CRW Bt corn, farmers might not be willing to pay as much even though they reported the expected damage in the absence of control was about the same for CRW and ECB.

Values for each survey were assigned randomly within stratifications defined by the IRM regulatory conditions and refuge configuration combinations. To test if this stratification induced selection bias, a probit regression was used to determine if the probability a farmer responded to the survey and answered the WTP question was influenced by the survey values. The probit estimates were not individually or jointly significant.

Statistical Analysis

Farmers answered either "yes" or "no" to whether they would be willing to plant the hypothetical hybrid in the next growing season. Therefore, a limited dependent variable model is appropriate. We chose the probit model while assuming a farmer's willingness to pay was log-linear in the product and IRM characteristics:[2]

$$\text{(1)} \qquad \ln(WTP) = \mathbf{X}_{PC}\beta_{PC} + \mathbf{X}_{IRM}\beta_{IRM}\,IRM\,Required + e = \mathbf{X}\beta + e,$$

where $\mathbf{X}_{PC}$ and $\mathbf{X}_{IRM}$ are row vectors of the product and IRM characteristics, β_{PC} and β_{IRM} are column vectors of parameters for the product and IRM characteristics, *IRM Required* is a dummy variable equal to 1 if the farmer was told IRM requirements were applicable, and e is a normally distributed random error with mean zero and variance σ^2. With this specification,

$$\text{(2)} \qquad \mathbf{X}_{PC}\beta_{PC} = \beta_{P1}Product\,1 + \beta_{P2}Product\,2 + \beta_{P3}Product\,3 + \beta_{P4}Product\,4 + \beta_{EMA}Export\ Market\ Approval$$

and

$$\text{(3)} \qquad \mathbf{X}_{IRM}\beta_{IRM} = \beta_{REQ} + \beta_{RS}Refuge\ Size + \beta_{RT}Refuge\ Treatment + \beta_{SM}Seed\ Mix + \beta_{MS}Multiple\ Strips + \beta_{BL}Blocks + \beta_{SF}Separate\ Field,$$

where *Product k* is a dummy variable equal to 1 for product k; *Export Market Approval* is a dummy variable equal to 1 if the product had export approval; *Refuge Size* is the size of the refuge in percentage of corn acreage; *Refuge Treatment* is a dummy variable equal to 1 if refuge insecticide treatments were permitted; and *Seed Mix*, *Multiple Strips*, *Blocks*, and *Separate Field* are dummy variables equal to 1 if seed mixes, multiple non-Bt strips, within-field non-Bt blocks, and separate non-Bt fields were permitted refuge configurations.

Equations (1)–(3) describe a typical hedonic model assuming a respondent's WTP is positive, which may not be the case for farmers ideologically or otherwise opposed to Bt corn because it is a genetically modified crop (e.g., organic farmers). To identify these farmers, the survey asked "no" respondents to indicate what motivated their response. If these respondents said "no" because they would "never plant Bt corn," they were excluded from the sample.

The probability the ith respondent says "yes" to the WTP question is the probability the farmer's WTP equals or exceeds the price premium P^i:

$$\Pr(WTP^i \geq P^i) = 1 - \Phi\left(\left(\ln(P^i) - \mathbf{X}^i\beta\right)\sigma^{-1}\right),$$

where $\Phi(\cdot)$ is the cumulative standard normal distribution function. Let Y^i be a dummy variable equal to 1 if the respondent said "yes." The log-likelihood function is:

$$\text{(4)} \qquad L = \sum_{i=1}^{N} \ln\left(Y^i\left(1 - \Phi\left(\left(\ln(P^i) - \mathbf{X}^i\beta\right)\sigma^{-1}\right)\right) + (1 - Y^i)\Phi\left(\left(\ln(P^i) - \mathbf{X}^i\beta\right)\sigma^{-1}\right)\right),$$

where N equals the number of respondents, which can be optimized for β_{PC}, β_{IRM}, and σ^2.

[2] A log-linear model was used because it provided a better fit and more intuitive coefficient estimates than the simpler linear model.

Some results of the analysis using equations (1)–(3) defied expectations, but seemed to have reasonable explanations given other survey responses. For example, the parameter for *Export Market Access* was positive, but not significant, which could be explained by the fact that half of the respondents used their harvest to feed livestock. Farmers also seemed to value Bt corn more, not less, when required to follow EPA IRM guidelines, a result possibly related to the fact that more than half the respondents indicated IRM was "very important." Finally, farmers appeared to value Bt corn less, not more, when they had the option to treat refuge with non-Bt insecticides, which may be due to a structural difference in the effect of refuge size and configuration requirements on the value of Bt corn.

The reasonableness of these explanations was explored by also estimating

$$(1') \qquad \mathbf{X}\beta = \mathbf{X}_{PC}\beta_{PC} + \left(\mathbf{X}_{IRM}\beta^{0}_{IRM} + \mathbf{X}_{IRM}\left(\beta^{1}_{IRM} - \beta^{0}_{IRM}\right) \textit{Refuge Treatment}\right) \textit{IRM Required}.$$

For equation (1′),

$$(2') \qquad \mathbf{X}_{PC}\beta_{PC} = \beta_{P1}\textit{Product}\,1 + \beta_{P2}\textit{Product}\,2 + \beta_{P3}\textit{Product}\,3 + \beta_{P4}\textit{Product}\,4 + \beta_{EMA}\textit{Export Market Access}\ (\textit{Farm Coop} + \textit{Feed Mill} + \textit{Grain Handler})$$

and

$$(3') \qquad \mathbf{X}_{IRM}\beta^{j}_{IRM} = \beta^{j}_{REQ} + \beta^{j}_{IMP}\textit{IRM Important} + \beta^{j}_{RS}\textit{Refuge Size} + \beta^{j}_{SM}\textit{Seed Mix} + \beta^{j}_{MS}\textit{Multiple Strips} + \beta^{j}_{BL}\textit{Blocks} + \beta^{j}_{SF}\textit{Separate Field}, \quad \text{for } j = 0, 1,$$

where $j = 0$ indicates no treatment option and $j = 1$ indicates a treatment option; *Farm Coop*, *Feed Mill*, and *Grain Handler* are dummy variables equal to 1 if the respondent marketed corn to a farmer cooperative, private feed mill, or independent grain handler in 2002;[3] and *IRM Important* is a dummy variable equal to 1 if the respondent indicated IRM was "very important."

Hypothesis Tests

The primary purpose of the survey was to estimate a farmer's cost of compliance with IRM requirements. Moreover, how different levels of insect control and export market approval affect a farmer's WTP for Bt corn was also of interest. These issues were explored by estimating a variety of models based on different restrictions for the product and IRM parameters.

Four specifications for the effect of the control spectrum on a farmer's WTP were explored. The first assumed the WTP did not depend on the control spectrum: $\beta_{P1} = \beta_{P2} = \beta_{P3} = \beta_{P4}$. The second assumed WTP only depended on the difference in ECB control:

[3] Rather than just sales to off-farm markets, the number of off-farm markets used by a farmer is included to increase variation in the independent variables and improve identification.

$\beta_{P1} = \beta_{P2}$, and $\beta_{P3} = \beta_{P4}$. The third assumed WTP only depended on the difference in CRW population control: $\beta_{P1} = \beta_{P3}$, and $\beta_{P2} = \beta_{P4}$. Finally, the fourth specification assumed WTP depended on the difference in CRW population control and the difference in ECB control, implying no product parameter restrictions.

Four alternative specifications for the effect of IRM policy on a farmer's WTP were explored for estimates based on equations (1)–(3). The first assumed the WTP did not depend on any IRM requirements: $\beta_{IRM} = \beta_{RS} = \beta_{RT} = \beta_{SM} = \beta_{MS} = \beta_{BL} = \beta_{SF} = 0$. The second assumed that only having IRM requirements mattered: $\beta_{RS} = \beta_{RT} = \beta_{SM} = \beta_{MS} = \beta_{BL} = \beta_{SF} = 0$. The third assumed that having IRM requirements mattered only in terms of the refuge size and treatment option: $\beta_{SM} = \beta_{MS} = \beta_{BL} = \beta_{SF} = 0$. Under the fourth specification, all facets of the IRM requirements were assumed to matter, implying no restrictions on the IRM parameters.

The expanded investigation [equations (1′)–(3′)] considered five sets of restrictions for the IRM policy regime separated by the treatment option. The first again assumed the requirements did not matter: $\beta^j_{IRM} = \beta^j_{IMP} = \beta^j_{RS} = \beta^j_{SM} = \beta^j_{MS} = \beta^j_{BL} = \beta^j_{SF} = 0$. The second assumed that only having IRM requirements mattered: $\beta^j_{IMP} = \beta^j_{RS} = \beta^j_{SM} = \beta^j_{MS} = \beta^j_{BL} = \beta^j_{SF} = 0$. The third assumed that how the IRM requirements mattered only depended on whether the respondent thought IRM was "very important": $\beta^j_{RS} = \beta^j_{SM} = \beta^j_{MS} = \beta^j_{BL} = \beta^j_{SF} = 0$. The fourth assumed that having IRM requirements only mattered in terms of the importance of IRM and refuge size: $\beta_{SM} = \beta_{MS} = \beta_{BL} = \beta_{SF} = 0$. The fifth assumed all facets of the IRM requirements mattered, implying no restrictions on the jth IRM parameters. The two different treatment options imply there are a total of 25 separate specifications for the effect of IRM on the WTP.

The initial estimates compared 16 specifications, many of which were nested. The expanded estimates compared 100 specifications, again many of which were nested. The likelihood-ratio statistic was used to compare nested models, while the likelihood dominance criterion (Pollak and Wales, 1991) was used to compare nonnested models.

Adoption, Welfare, and Compliance Cost Estimates

The survey results provide an opportunity to estimate Bt corn adoption, welfare benefits, and IRM compliance cost assuming the errors reflect unobserved heterogeneity among Minnesota farmers. To explain how, some additional notation is helpful. Let $\mathbf{X}(\delta, \theta, \omega)$ be the vector of explanatory variables as it depends on the observed product (δ, e.g., control spectrum and export approval), IRM (θ, e.g., refuge size, configuration, and treatment option), and farmer (ω, e.g., importance of IRM and number of off-farm grain markets utilized) characteristics. Let ψ be the proportion of total corn acres operated by farmers who said they would never plant Bt corn. Let $\lambda(\omega)$ be the proportion of corn acres operated by farmers with individual characteristics $\omega \in \Omega$ who might plant Bt corn, where Ω is the cross-product of *IRM Important* $\in \{0, 1\}$ and *Farm Coop + Feed Mill + Grain Handler* $\in \{0, 1, 2, 3\}$. Finally, let θ_R be the required proportion of refuge corn acreage and P be the price premium.

Bt corn adoption as a proportion of total corn acres is estimated by first considering the probability a farmer adopts Bt corn given the price, product, IRM, and farmer characteristics: $1 - \Phi((\ln(P) - \mathbf{X}(\delta, \theta, \omega)\beta)\sigma^{-1})$. This probability does not apply to farmers who said they would never plant Bt corn, so multiplying by $1 - \psi$ takes these farmers into account. Multiplying again by $1 - \theta_R$ adjusts adoption to reflect the required proportion of refuge planted by adopters. Finally, to aggregate over farmers with different characteristics, a weighted average is taken based on the proportion of total crop acreage operated by farmers with different characteristics:

$$q(P \mid \delta, \theta) = \sum_{\omega \in \Omega} \left(1 - \Phi\left(\left(\ln(P) - \mathbf{X}(\delta, \theta, \omega)\hat{\beta}\right)\hat{\sigma}^{-1}\right)\right)(1 - \psi)(1 - \theta_R)\lambda(\omega). \tag{5}$$

Equation (5) provides an estimate of the proportion of corn acreage planted with Bt corn given the price, product, and IRM characteristics.

The welfare benefit of Bt corn is calculated by first considering the net benefit to a farmer from adopting Bt corn given the price, product, IRM, and farmer characteristics: $WTP - P = e^{\mathbf{X}(\delta,\theta,\omega)\beta + e} - P$. A farmer adopts Bt corn when this net benefit is positive: $WTP > P$, or $e > \ln(P) - \mathbf{X}(\delta, \theta, \omega)\beta$. Therefore, the average net benefit given the price, product, IRM, and farmer characteristics is the conditional average:

$$FB(P \mid \delta, \theta, \omega) = \int_{\ln(P) - \mathbf{X}(\delta,\theta,\omega)\beta}^{\infty} \left(e^{\mathbf{X}(\delta,\theta,\omega)\beta + e} - P\right) \times \frac{\frac{1}{\sqrt{2\pi\sigma}} e^{-(e^2/2\sigma^2)}}{1 - \Phi\left(\left(\ln(P) - \mathbf{X}(\delta, \theta, \omega)\beta\right)\sigma^{-1}\right)} de. \tag{6}$$

Rearranging terms, this average can be rewritten as:

$$e^{\mathbf{X}(\delta,\theta,\omega)\beta} \left(\frac{\int_{\ln(P) - \mathbf{X}(\delta,\theta,\omega)\beta}^{\infty} \frac{1}{\sqrt{2\pi\sigma}} e^{-((e^2 2\sigma^2 e)/2\sigma^2)} de}{1 - \Phi\left(\left(\ln(P) - \mathbf{X}(\delta, \theta, \omega)\beta\right)\sigma^{-1}\right)} \right) - P \left(\frac{\int_{\ln(P) - \mathbf{X}(\delta,\theta,\omega)\beta}^{\infty} \frac{1}{\sqrt{2\pi\sigma}} e^{-(e^2/2\sigma^2)} de}{1 - \Phi\left(\left(\ln(P) - \mathbf{X}(\delta, \theta, \omega)\beta\right)\sigma^{-1}\right)} \right).$$

Completing the square for $e^2 - 2\sigma^2 e$, and recognizing that

$$\int_{\alpha}^{\infty} \frac{1}{\sqrt{2\pi\sigma}} e^{-(e^2/2\sigma^2)} de = 1 - \Phi(\alpha\sigma^{-1}),$$

lets the average be written as

$$e^{\mathbf{X}(\delta,\theta,\omega)\beta + 0.5\sigma^2} \left(\frac{\int_{\ln(P) - \mathbf{X}(\delta,\theta,\omega)\beta}^{\infty} \frac{1}{\sqrt{2\pi\sigma}} e^{-(e-\sigma^2)^2/2\sigma^2} de}{1 - \Phi\left(\left(\ln(P) - \mathbf{X}(\delta, \theta, \omega)\beta\right)\sigma^{-1}\right)} \right) - P.$$

Note that

$$\int_{\alpha}^{\infty} \frac{1}{\sqrt{2\pi\sigma}} e^{-(e-\sigma^2)^2/2\sigma^2} de = 1 - \Theta(\alpha),$$

where $\Theta(\alpha)$ is a cumulative normal distribution function with mean zero and variance σ^2. Therefore, $\Theta(\alpha) = \Phi((\alpha - \sigma^2)\sigma^{-1})$, such that equation (6) simplifies to:

$$(6') \qquad FB(P \mid \delta, \theta, \omega) = e^{\mathbf{X}(\delta,\theta,\omega)\beta + 0.5\sigma^2} \frac{1 - \Phi\big((\ln(P) - \mathbf{X}(\delta, \theta, \omega)\beta)\sigma^{-1} - \sigma\big)}{1 - \Phi\big((\ln(P) - \mathbf{X}(\delta, \theta, \omega)\beta)\sigma^{-1}\big)} - P.$$

Multiplying by $1 - \psi$ and $1 - \theta_R$ adjusts for farmers who said they would never plant Bt corn and the refuge requirement. Finally, these average net benefits are aggregated across farmers with different characteristics, taking into account the probability of adoption:

$$(7) \qquad FB(P \mid \delta, \theta) = \sum_{\omega \in \Omega} FB(P \mid \delta, \theta, \omega)\Big(1 - \Phi\big((\ln(P) - \mathbf{X}(\delta, \theta, \omega)\beta)\sigma^{-1}\big)\Big) \times (1 - \psi)(1 - \theta_R)\lambda(\omega).$$

Equation (7) reflects the total net benefit of Bt corn to farmers per acre of corn.

The per acre net benefit to the seed corn industry is $P - C$, where C is the added cost of producing Bt instead of conventional seed. Multiplying by the adoption rate yields:

$$(8) \qquad IB(P, C \mid \delta, \theta) = (P - C)q(P \mid \delta, \theta),$$

which reflects the total net benefit to the seed corn industry from sales of Bt seed corn per acre of corn. Combining the results in equation (7) and (8) yields the welfare benefit of Bt corn per acre of corn as a function of the price, the added cost of producing Bt seed, product, and IRM characteristics: $WB(P, C \mid \delta, \theta) = FB(P \mid \delta, \theta) + IB(P, C \mid \delta, \theta)$.

The net benefit to farmers from planting an acre of Bt corn can also be used to estimate compliance costs. For example, for a 20% refuge, a farmer's compliance costs can be interpreted as the expected net benefit lost on one acre of conventional corn planted as refuge for every four acres of Bt corn. In general, this average compliance cost is:

$$(9) \qquad CC(P \mid \delta, \theta) = FB(P \mid \delta, \theta)\frac{\theta_R}{(1 - \theta_R)}.$$

Using these equations to estimate adoption, welfare benefits, and compliance costs requires information on the price premium, added cost of producing Bt seed, proportion of corn acreage operated by farmers who would never plant Bt corn, and distribution of corn acres operated by farmers with different characteristics who might plant Bt corn, as well as the estimates for β, and σ^2 from equations (1)–(3) or (1′)–(3′). For the CRW, and CRW and ECB Bt corn price premiums, \$17 and \$24 per acre, respectively, are used based on information provided by local farmer cooperatives. The marginal cost of producing Bt seed corn is considered negligible because once the fixed cost of introducing the Bt trait into seed stock is incurred, the marginal cost of propagating seed is essentially the same for Bt and conventional seed (i.e., $C = 0$). The proportion of corn acres operated by farmers who would never plant Bt corn is taken directly from survey responses. The proportion of corn acres operated by farmers with different characteristics who might plant Bt corn is also taken directly from survey responses.

Results

Overview of Respondents

The average survey respondent was male, 52 years old with at least a high school degree, and farmed about 500 acres. The majority (56%) worked off-farm, with 39% producing livestock as well as corn. The expected price per bushel of corn was about $2 with an expected yield of 137 bushels per acre. Respondents confirmed the importance of CRW and ECB as pests, with 55.4% and 83.9% reporting noticeable damage from each, respectively, in the past five years. On average, respondents expected losses from either CRW or ECB to be around 17 bushels per acre without control. The most important factors for deciding when and how to control these pests were costs, followed by yield and harvest time. The majority of respondents had not previously experienced insect resistance problems. The self-reported IRM compliance rate was high, 72%, but still lower than results reported by ABSTC (2002). More than 50% reported being "very concerned" about ECB resistance to Bt corn.

Of the 630 farmers who responded to the WTP question (i.e., whether they would be willing to plant the hypothetical hybrid in the next growing season), 526 chose "no." Of these, 59, or about 11% (4.1% of the reported corn acreage), indicated they would never plant Bt corn. This left 571 observations for analysis, of which one in five chose "yes." Of the remaining sample, 53.4% indicated IRM was "very important," while 49%, 14.5%, and 26.8%, respectively, indicated they sold grain to a farmer cooperative, private feed mill, or independent grain handler. In terms of the distribution of corn acres operated by farmers with different characteristics, 7.8%, 22.5%, 6.5%, and 1.7% were operated by farmers who indicated IRM was "not very important" and sold grain to 0 to 3 off-farm markets, and 10%, 37.5%, 9.9%, and 4.1% were operated by farmers who indicated IRM was "very important" and sold grain to 0 to 3 off-farm markets.

Hypothesis Tests

Table 1 reports the maximized log likelihood (number of parameters estimated) for the 16 combinations of the hypotheses regarding how IRM characteristics (rows [a]–[d]) and the proposed hybrid's control spectrum (columns [1]–[4]) influenced a farmer's WTP for the initial model specification [equations (1)–(3)]. The right-hand side of the table reports χ^2 likelihood-ratio statistics (degrees of freedom) for row-wise comparisons of the models in columns [2]–[4] to the model in column [1]. The bottom half of the table reports χ^2 likelihood-ratio statistics (degrees of freedom) for column-wise comparisons of the models in rows [a]–[c] to the model in row [d] and for the model in row [b] to the model in row [c].

The results in table 1 favor the model with ECB control effects, column [2], and IRM required, refuge size, and refuge treatment effects, row [c]. For the column-wise comparisons, the models in columns [3] and [4] are always rejected (at a 5% significance level) in favor of the models in column [1]. The models in column [2] are never rejected in favor of models in column [1]. For row-wise comparisons, the models in row [d], but not the models in rows [b] or [c], are rejected in favor of the models in row [a]. The models in row [b] are also always rejected in favor of models in row [c].

Table 2 reports the coefficient estimates (t-statistics) for the unrestricted model from equations (1)–(3) and the preferred model identified from table 1. For the preferred

Table 1. Maximized Log Likelihood and Likelihood Ratio (χ^2) Model Comparisons for Specifications Without Export Market Interactions, Structural Treatment Effects, and IRM Importance

	Control Spectrum Characteristics: Maximized Log Likelihood (no. of parameters est'd.)				Model Comparisons: χ^2 (d.f.)		
IRM Characteristics	[1] No Spectrum Effect	[2] ECB Control Effect	[3] CRW Control Effect	[4] CRW & ECB Control Effect	Col. [1] vs. Col. [2]	Col. [1] vs. Col. [3]	Col. [1] vs. Col. [4]
[a] No IRM	-253.42 (3)	-251.37 (4)	-253.36 (4)	-250.53 (6)	4.09** (1)	0.11 (1)	5.77 (3)
[b] IRM Required	-252.72 (4)	-250.64 (5)	-252.66 (5)	-249.81 (7)	4.15** (1)	0.13 (1)	5.82 (3)
[c] IRM Required, Size, & Treatment	-247.60 (6)	***-245.22*** ***(7)***	-247.60 (7)	-244.51 (9)	4.77** (1)	0.01 (1)	6.19 (3)
[d] IRM Required, Size, Treatment, & Configuration	-245.46 (10)	-243.03 (11)	-245.46 (11)	-242.42 (13)	4.86** (1)	0.00 (1)	6.07 (3)
	Model Comparisons: χ^2 (d.f.)						
Row [a] vs. Row [b]	15.91** (7)	16.69** (7)	15.81** (7)	16.22** (7)			
Row [a] vs. Row [c]	14.52** (6)	15.23** (6)	14.39** (6)	14.78** (6)			
Row [a] vs. Row [d]	4.29 (4)	4.38 (4)	4.28 (4)	4.17 (4)			
Row [b] vs. Row [c]	10.23*** (2)	10.85*** (2)	10.11*** (2)	10.61*** (2)			

Note: Single, double, and triple asterisks (*) denote statistical significance at the 10%, 5%, and 1% levels, respectively, for a single-tailed test.

model, the coefficient estimates for CRW and ECB products exceed the estimates for CRW products, which implies farmers value a product that controls CRW and ECB more than one that only controls CRW. This result is as expected and statistically significant. The coefficient for export market approval is positive, indicating a farmer's WTP is higher when there is export approval. The coefficient for refuge size is negative, suggesting a farmer's WTP is lower when the refuge size requirement is higher. While these two estimates have intuitive signs, their lack of statistical significance should be noted. The constant coefficient for IRM required is positive, revealing that farmers actually value IRM regulations. The coefficient for the refuge treatment option is negative, showing farmers prefer not having the option to treat refuge with non-Bt insecticides. Both these coefficients have unexpected signs and are statistically significant. Table 2 indicates a farmer's WTP was not influenced by configuration when all four configurations were jointly considered.

The lack of statistical significance of the export approval and refuge size variables, and the unanticipated direction and strong significance of the IRM required and treatment option variables was initially disconcerting. Upon reflection, however, reasonable explanations seemed to emerge. For example, many respondents fed corn to livestock and many were "very concerned" about Bt resistance.

Table 2. Parameter Estimates for Unrestricted and Preferred Models Without Export Market Interactions, Structural Treatment Effects, and IRM Importance

Parameter	Unrestricted Model		Preferred Model
	75% CRW Control	***95% CRW Control***	
CRW Control	1.03**	1.23***	1.07***
	(2.19)	(2.85)	(2.48)
CRW and ECB Control	1.62***	1.43***	1.46***
	(4.13)	(3.68)	(3.83)
Export Market Access	0.082		0.12
	(0.45)		(0.66)
	IRM Required		***IRM Required***
Constant	0.73*		0.84**
	(1.58)		(2.21)
Refuge Size	-0.0074		-0.0079
	(1.09)		(1.21)
Refuge Treatment	-0.53***		-0.56***
	(2.40)		(2.57)
Seed Mix	0.24		
	(1.00)		
Multiple Strips	-0.31*		
	(1.45)		
Block	0.30*		
	(1.41)		
Separate Field	-0.026		
	(0.11)		
Standard Deviation	1.35		1.38
Maximized Log Likelihood	-242.42		-245.22
Estimated Parameters	13		7
No. of Observations	571		571

Notes: Single, double, and triple asterisks (*) denote statistical significance at the 10%, 5%, and 1% levels, respectively, for a single-tailed test. Values in parentheses are t-statistics.

To explore these explanations, we estimated the model with equations (1′)–(3′) based on restricting the control spectrum and IRM requirements with and without the refuge treatment option. Table 3 reports the unrestricted specification of the model and the preferred specification based on comparisons analogous to those reported in table 1.[4]

The preferred model in table 3 dominates the preferred model in table 2 based on the likelihood dominance criterion (5% significance). With seven parameters for the preferred model in table 2 and nine parameters for the preferred model in table 3, the lower and upper thresholds for the likelihood dominance criterion with 5% significance are 1.40 and 1.99. Since the difference in the maximized log likelihood of the two models (14.06) exceeds both thresholds, the model with the most parameters, the preferred model in table 3, dominates the model with the fewest parameters, the preferred model in table 2.

[4] A full account and summary of the 100 models is available from the authors on request.

Table 3. Parameter Estimates for Unrestricted and Preferred Models With Export Market Interactions, Structural Treatment Effects, and IRM Importance

Parameter	Unrestricted Model		Preferred Model	
	75% CRW Control	***95% CRW Control***		
CRW Control	1.03**	1.16***	1.08***	
	(2.17)	(2.66)	(2.57)	
CRW and ECB Control	1.64***	1.38***	1.46***	
	(4.21)	(3.53)	(3.93)	
Export Market Access × No. of Off-Farm Markets	0.23*		0.25**	
	(1.53)		(1.75)	
	IRM Required:		***IRM Required:***	
	No Treatment Option	***Treatment Option***	***No Treatment Option***	***Treatment Option***
Constant	0.74*	-1.06**	0.53	-0.36
	(1.38)	(1.66)	(1.28)	(0.97)
IRM Important	0.98***	0.71**	1.02***	0.68**
	(2.88)	(2.25)	(3.02)	(2.30)
Refuge Size	-0.021**	0.0086	-0.021**	
	(2.05)	(0.84)	(2.13)	
Seed Mix	0.18	0.33		
	(0.58)	(0.92)		
Multiple Strips	-0.32	-0.20		
	(1.12)	(0.61)		
Block	-0.0067	0.62*		
	(0.02)	(1.72)		
Separate Field	-0.19	0.19		
	(0.57)	(0.48)		
Standard Deviation	1.31		1.33	
Maximized Log Likelihood	-226.93		-231.16	
Estimated Parameters	20		9	
No. of Observations	571		571	

Notes: Single, double, and triple asterisks (*) denote statistical significance at the 10%, 5%, and 1% levels, respectively, for a single-tailed test. Values in parentheses are t-statistics.

The preferred model in table 3 helps explain most of the weak anticipated and strong unanticipated results for the preferred model in table 2. By interacting export market approval with the number of off-farm corn markets, strengthened significance of the anticipated positive effect is achieved. Increasing the size of the required refuge significantly decreases a farmer's willingness to pay for Bt corn if there are no other refuge control options available. Alternatively, when refuge insecticide treatments are permissible, the size of refuge does not appear to matter. Including the perceived importance of managing resistance helps explain the potential for IRM having a positive effect on a farmer's willingness to pay, while the treatment option has a negative effect. Farmers who believe IRM is important value Bt corn more if they know all farmers are required to follow IRM protocols. This value appears stronger when there is no refuge treatment option possibly because there is still debate regarding the effectiveness of IRM when refuge populations are suppressed by insecticide treatments.

Adoption, Welfare, and Compliance Costs

Table 4 reports estimates and 90% confidence intervals for adoption, the welfare benefit, percentage of this benefit accruing to farmers, and farmer compliance costs for the preferred model in table 3 under a variety of assumptions regarding IRM characteristics for CRW Bt corn. Table 5 reports the same estimates for CRW and ECB Bt corn. The first estimates reported in both tables are based on current IRM requirements for Minnesota (20% treatable refuge in within-field blocks, multiple within-field strips, or adjacent fields). Subsequent estimates in the tables consider three other policy alternatives: an increase in refuge size to 50%, the elimination of the refuge treatment option, and both. Figure 1 shows how sensitive the results for the current IRM policy are to the price premium.

As reported in table 4, the predicted adoption of CRW Bt corn at a price premium of $17 per acre of Bt corn for current IRM requirements is 8.4% assuming the product is not export approved. The total benefit is estimated to be $3.42 per acre of corn. With about 7 million acres of corn planted each year in Minnesota, the total benefit would be about $24 million. Almost 60% of this benefit, or $14 million, is estimated to accrue to farmers, with the balance accruing to the seed corn industry. Compliance costs are estimated to be $0.50 per acre of corn, or $3.5 million total. With export approval, adoption of CRW Bt corn is estimated to increase to 11.9%, with the total benefit increasing to $37.6 million, $23.4 million accruing to farmers and $14.2 accruing to the seed corn industry. Compliance costs are also estimated to be higher: $5.9 million total.

The estimated adoption of CRW and ECB Bt corn as reported in table 5 is 12.3% with export approval and 8.7% without, assuming the price premium is $24 per acre of Bt corn and current IRM requirements. The total welfare benefit of Bt corn is then estimated to be $55.6 and $35.5 million with and without export approval, respectively. The distribution of benefits between farmers and the seed industry remains close to 3 to 2, with a slightly higher proportion accruing to farmers if Bt corn is export approved. The respective compliance cost estimates are $8.7 and $5.2 million total with and without export approval.

For comparison, Minnesota adoption for all Bt corn varieties increased by 11 percentage points or 33.3% since the introduction of CRW active Bt corn (USDA/NASS, 2005). This increased adoption is within the range of the adoption estimates reported in table 4. However, some caution should be exercised when interpreting these numbers due to a variety of confounding factors. For example, the adoption trend for ECB Bt corn was still increasing in 2002, so some of this increased adoption may be due to further increases in ECB Bt corn adoption. Alternatively, some farmers may have switched from ECB to CRW active Bt corn.

Alston et al. (2002) found the total benefit for adopting CRW Bt corn in 2000 would have been about $460 million, with 63% of this benefit accruing to farmers and 37% accruing to the seed corn industry. Roughly $40.3 million of this $460 million can be attributed to Minnesota, since it contributes about 9% to U.S. corn production annually. Dividing this figure by 7 million yields a per acre benefit of $5.76, which lies just outside our 90% confidence interval if Bt corn is not export approved, but is well within the 90% confidence interval if Bt corn is export approved.

Alternatively, survey respondents reported expected losses of 17 bushels per acre from CRW and 17 bushels per acre from ECB if nothing is done to control these pests.

Table 4. Estimated Bt Corn Adoption, Welfare Benefits, and IRM Compliance Costs with [5th, 95th] Percent Confidence Intervals for Alternative IRM Policies for CRW Bt Corn

	CRW Bt Corn ($17 price premium)			
	Not Export Approved		Export Approved	
Description	Estimate	Confidence Intervals	Estimate	Confidence Intervals
	Current IRM Requirements [a]			
Adoption (% of corn acres)	8.4	[5.0, 11.8]	11.9	[6.9, 16.9]
Welfare Benefit ($/acre of corn)	3.42	[1.35, 5.48]	5.37	[1.78, 8.95]
Farmer Benefit (% of welfare benefit)	58.3	[43.8, 72.9]	62.3	[47.2, 77.4]
Farmer Compliance Cost ($/acre of corn)	0.50	[0.09, 0.90]	0.84	[0.10, 1.57]
	Current IRM Requirements With 50% Instead of 20% Refuge			
Adoption (% of corn acres)	5.2	[3.1, 7.4]	7.4	[4.3, 10.6]
Welfare Benefit ($/acre of corn)	2.13	[0.85, 3.42]	3.35	[1.11, 5.59]
Farmer Benefit (% of welfare benefit)	58.3	[43.8, 72.9]	62.3	[47.2, 77.4]
Farmer Compliance Cost ($/acre of corn)	1.25	[0.24, 2.25]	2.09	[0.26, 3.92]
	Current IRM Requirements Without Treatment Option			
Adoption (% of corn acres)	18.5	[13.9, 23.2]	23.7	[17.6, 29.8]
Welfare Benefit ($/acre of corn)	9.89	[4.18, 15.60]	14.50	[5.06, 23.95]
Farmer Benefit (% of welfare benefit)	68.1	[53.1, 83.2]	72.2	[57.2, 87.2]
Farmer Compliance Cost ($/acre of corn)	1.68	[0.37, 3.00]	2.62	[0.40, 4.83]
	Current IRM Requirements Without Treatment Option, and 50% Instead of 20% Refuge			
Adoption (% of corn acres)	6.1	[2.9, 9.3]	8.5	[4.4, 12.5]
Welfare Benefit ($/acre of corn)	2.65	[0.58, 4.73]	4.09	[0.89, 7.29]
Farmer Benefit (% of welfare benefit)	60.8	[45.0, 76.6]	64.8	[48.8, 80.9]
Farmer Compliance Cost ($/acre of corn)	1.61	[0.00, 3.23]	2.65	[0.01, 5.30]

[a] Current IRM requirements include 20% treatable refuge in within-field blocks, multiple within-field strips, or adjacent fields.

These respondents also reported $2 per bushel as the expected corn price. With 95% damage control and the adoption rates reported in tables 4 and 5, the welfare benefit from adopting Bt corn would be $3.84 and $2.70 per acre of corn for CRW Bt corn with and without export approval, and $7.96 and $5.63 for CRW and ECB Bt corn with and without export approval. All of these values fall within the 90% confidence intervals.

Policy Implications

The WTP estimates reported for the preferred model in table 3 provide an opportunity to consider how alternative IRM policies might effect adoption, welfare, and farmer compliance costs. While it is possible to explore a variety of policy alternatives with these estimates, further analysis is focused on two proposals recently considered by the EPA.

Table 5. Estimated Bt Corn Adoption, Welfare Benefits, and IRM Compliance Costs with [5th, 95th] Percent Confidence Intervals for Alternative IRM Policies for CRW and ECB Bt Corn

	CRW and ECB Bt Corn ($24 price premium)			
	Not Export Approved		Export Approved	
Description	Estimate	Confidence Intervals	Estimate	Confidence Intervals
		Current IRM Requirements [a]		
Adoption (% of corn acres)	8.7	[5.5, 11.9]	12.3	[8.1, 16.5]
Welfare Benefit ($/acre of corn)	5.07	[1.84, 8.29]	7.94	[2.73, 13.15]
Farmer Benefit (% of welfare benefit)	58.7	[43.4, 74.0]	62.7	[47.0, 78.4]
Farmer Compliance Cost ($/acre of corn)	0.74	[0.10, 1.39]	1.24	[0.14, 2.35]
		Current IRM Requirements With 50% Instead of 20% Refuge		
Adoption (% of corn acres)	5.5	[3.4, 7.5]	7.7	[5.1, 10.3]
Welfare Benefit ($/acre of corn)	3.7	[1.15, 5.18]	4.96	[1.70, 8.22]
Farmer Benefit (% of welfare benefit)	58.7	[43.4, 74.0]	62.7	[47.0, 78.4]
Farmer Compliance Cost ($/acre of corn)	1.86	[0.24, 3.48]	3.11	[0.35, 5.87]
		Current IRM Requirements Without Treatment Option		
Adoption (% of corn acres)	19.1	[13.6, 24.6]	24.3	[18.2, 30.5]
Welfare Benefit ($/acre of corn)	14.57	[4.61, 24.52]	21.31	[6.05, 36.58]
Farmer Benefit (% of welfare benefit)	68.5	[52.6, 84.5]	72.6	[56.9, 88.3]
Farmer Compliance Cost ($/acre of corn)	2.50	[0.24, 4.75]	3.87	[0.29, 7.44]
		Current IRM Requirements Without Treatment Option, and 50% Instead of 20% Refuge		
Adoption (% of corn acres)	6.4	[2.9, 9.8]	8.7	[4.7, 12.8]
Welfare Benefit ($/acre of corn)	3.93	[0.55, 7.30]	6.04	[1.07, 11.01]
Farmer Benefit (% of welfare benefit)	61.2	[44.5, 77.9]	65.2	[48.5, 82.0]
Farmer Compliance Cost ($/acre of corn)	2.40	[−0.23, 5.04]	3.94	[−0.22, 8.10]

[a] Current IRM requirements include 20% treatable refuge in within-field blocks, multiple within-field strips, or adjacent fields.

In 2002, the EPA called a meeting of the Federal Insecticide, Fungicide, and Rodenticide Act's (FIFRA's) Scientific Advisory Panel (SAP) to evaluate the IRM requirements being recommended by Monsanto for CRW active Bt corn. One of the committee's charges was to offer an opinion on the adequacy of 20% refuge. The result of the meeting was a split opinion. The majority of the panel recommended 50% refuge instead of 20% (U.S. EPA, 2002). The majority cited a lack of information to justify their more conservative recommendation.

Tables 4 and 5 provide estimates of how an increase in the refuge size requirement from 20% to 50% would affect adoption, the welfare benefit, percentage of this benefit accruing to farmers, and farmer compliance costs for both varieties of Bt corn. Regardless of product characteristics, increasing the size of refuge would diminish the percentage of corn acreage planted with Bt corn—for example, from 8.4% to 5.2% for

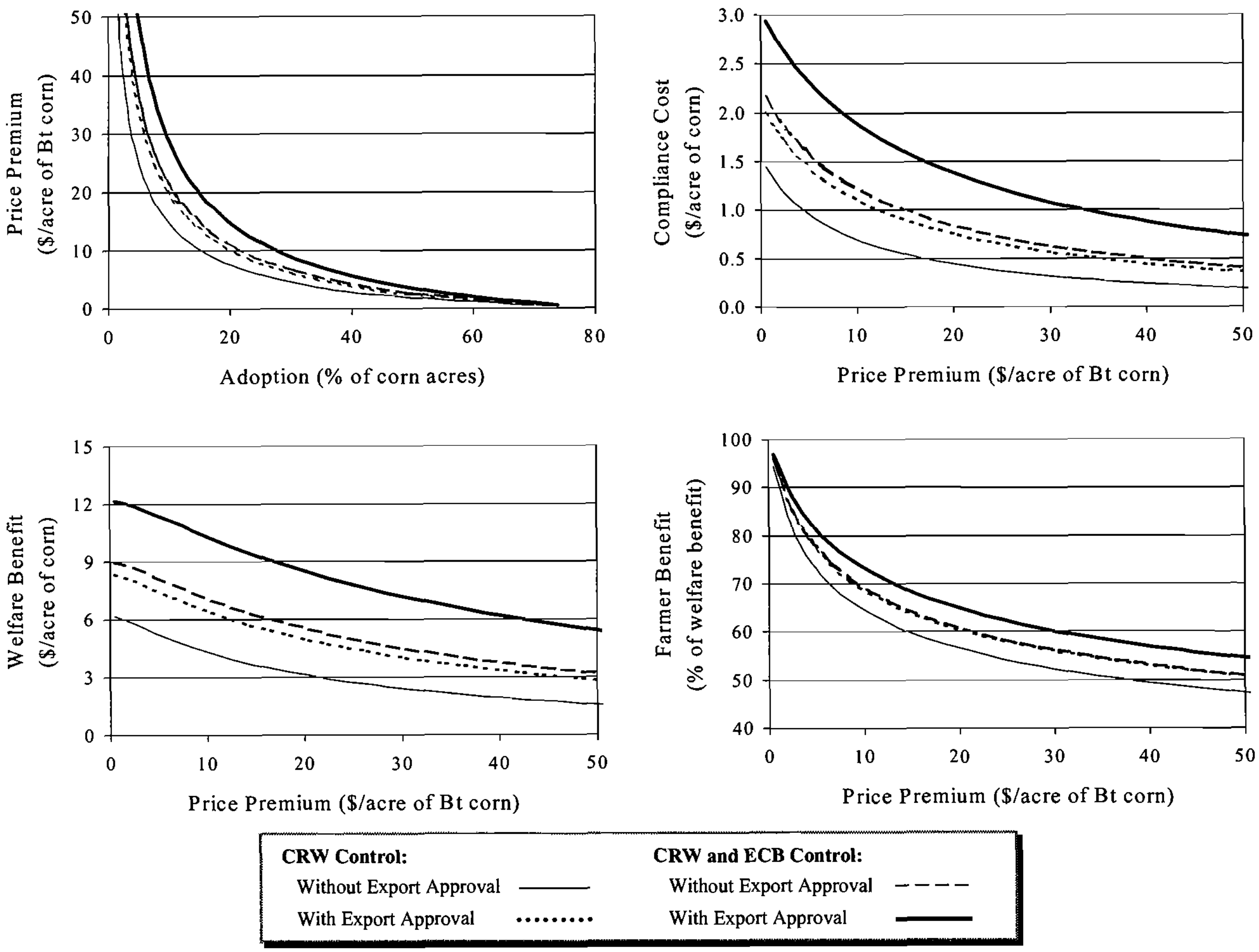

Figure 1. Sensitivity of Bt corn adoption, welfare benefits, and IRM compliance costs to price premiums for current IRM requirements

CRW Bt corn without export approval. The welfare benefit would also decrease substantially, while the distribution of these benefits would be unchanged. Compliance costs would increase, which would put additional pressure on farmers to ignore IRM regulations. It is important to note that these results are driven exclusively by a change in the percentage of Bt corn acreage a farmer can plant and not by a change in estimated WTP, because refuge size does not influence the WTP when there is the treatment option.

With some reluctance, the EPA currently allows refuge to be treated with non-Bt insecticides. Originally, the EPA did not allow refuge treatment because it might hinder IRM success. Industry requested a change in this policy, so farmers could reduce refuge losses in years of severe pest infestation. The EPA agreed to the industry's request because simulation models suggested refuge treatments would not substantially increase the risk of resistance. Still, the EPA has reserved the right to eliminate the treatment option if future research shows a more substantial threat to IRM success.

Tables 4 and 5 also provide estimates of adoption, the welfare benefit, percentage of this benefit accruing to farmers, and farmer compliance costs without the treatment option for CRW Bt corn, and CRW and ECB Bt corn, respectively. Interestingly, the results appear to contradict industry arguments. The model predicts that eliminating refuge treatments would have a positive effect on adoption and welfare, with most of the increased welfare benefit accruing to farmers. The results also suggest compliance costs would increase, which would provide a stronger incentive for farmers to ignore the IRM requirements. These findings contradict industry arguments because the estimates in table 3 imply that farmers who believe IRM is "very important" value an effective IRM requirement. The estimates in table 3 also indicate that all farmers prefer IRM requirements without the treatment option holding refuge size constant, suggesting they may harbor the same concerns as the EPA regarding the effectiveness of a treated refuge.

The final results in tables 4 and 5 consider the elimination of the treatment option and an increase in the refuge size from 20% to 50%. In this instance, the adoption of Bt corn is predicted to fall, as is the welfare benefit. The percentage of the welfare benefit accruing to farmers increases slightly, while farmer compliance costs increase substantially.

Conclusions

The purpose of this analysis was to explore the potential for using the CV method to estimate how different components of the EPA's IRM requirements influence the welfare benefits of Bt corn and farmer compliance costs. While CV methods are commonly used in natural resource damage assessment and other venues, concerns about the validity and consistency of the method persist.

The CV estimates reported in this paper are consistent with the increases in Bt corn adoption observed in Minnesota since the commercial introduction of CRW active Bt corn, but there are confounding factors that do not completely rule out coincidence. Estimates of the welfare benefits appear externally consistent with previously reported results, and internally consistent with the expected damages from CRW and ECB reported by survey respondents. Still, some results raise questions. For example, farmers prefer having IRM requirements if they think IRM is "very important." While the direction of this result may be reasonably explained by farmers valuing the sustainability of Bt corn afforded by IRM requirements, the magnitude seems high. Another difficult to explain result is the negative effect of the refuge treatment option on adoption and welfare. Again, the direction of this result may be reasonably explained by farmers valuing the sustainability of Bt corn if they are concerned that refuge treatments hinder IRM success. Unfortunately, the survey did not ask farmers if they harbored such concerns, so this hypothesis could not be explored further.

Characterizing the demand for new plant-incorporated-protectants like Bt corn in terms of a variety of reasonable regulatory levers provides an opportunity to refine regulatory policy in response to important socioeconomic factors that can contribute to or hinder regulatory success. Without this type of information, policy can take large steps in the wrong direction resulting in unnecessarily high regulatory costs or unacceptably high risks of policy failure. The CV method used in this research appears to do a good job in capturing the benefits of CRW active Bt corn, but the reasonableness of results regarding the costs of specific IRM requirements appears mixed. Therefore, further research to develop new and improve existing methodologies is warranted.

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Appendix:
Referendum WTP Question from Survey

Note: Survey items that varied are shown in *bold italics*.

Please tell us about the value of a new program for managing insects:

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

To reduce the chance of ECB resistance to Bt corn, EPA guidelines currently request farmers to plant non-Bt corn hybrids for refuge. The guidelines specify how much refuge corn to plant, where to plant refuge corn, and when to use insecticides on refuge corn. Similar guidelines are being considered for the new Bt corn hybrids. For example, the guidelines for the new hybrid might include:

- Planting at least ***40 percent*** of your total corn acreage to non-Bt corn for refuge.
- ***Planting refuge corn in a seed mix with your Bt corn.***
- ***Using insecticides other than Bt microbial sprays on your refuge corn to control CRW only when economic thresholds are reached (as those recommended by local or regional professionals, such as Extension agents or crop consultants).***

D1. Suppose the example of a new Bt corn hybrid described above:

- was registered by the EPA for commercial sale to farmers;
- was the same as the non-Bt corn hybrids you commonly plant except for its insect control benefits (for example, it had the same maturity, yield potential, and herbicide tolerance);
- ***was approved for marketing in the U.S. and all major corn export markets;*** and
- ***could be planted only if you follow all of the guidelines described above.***

Would you have planted this new hybrid in 2002 if it were available and its seed costs were ***$5*** per acre higher than the non-Bt hybrids you commonly plant?

(Please ✓ your answer)

❑ Yes ❑ No