Moral Hazard and Bt Corn Refuge

Paul D. Mitchell

and

En "John" Zhu

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Short Abstract

Using a principal-agent model, we find the optimal subsidy contract that induces grower compliance with Bt corn refuge requirements for managing insect resistance when asymmetric information exists concerning grower behavior. The optimal contract balances the cost of monitoring and the benefit of reducing the likelihood of insect resistance.

Authors are assistant professor and Ph.D. student, Department of Agricultural Economics, Texas A&M University, 333 Blocker Building, College Station, TX 77843-2124, voice (979) 845-6322, fax (979) 862-1563, e-mail p-mitchell@tamu.edu.

Bt corn is created by inserting selected exotic DNA into the corn plant's own DNA. Bt corn hybrids produce an insecticidal protein derived from the bacterium *Bacillus thuringiensis*, commonly called Bt. These hybrids provide protection against the European corn borer (ECB) usually far greater than optimally timed insecticides. Losses resulting from European corn borer damage and control costs exceed $1 billion each year (Mason et al.).

Since its commercial introduction in 1996, Bt corn has proven to be an effective new tool for managing the ECB and offers a sound economic return. The direct and indirect benefits of Bt corn have resulted in rapid and widespread adoption: in 1999, an estimated 25 percent of U.S. corn acreage was planted to Bt corn, in 2000 and 2001, Bt corn still represented almost 20% of U.S. corn acreage (USDA-NASS 2002).

However, with all the excitement over the benefits, various concerns also emerge. Can European corn borer develop resistance to Bt corn? At least seven laboratory colonies of three insect pest species have developed resistance to Bt proteins, but no viable field population of a resistant insect pest has been detected (Tabashnik et al.). Biological factors contributing to the development of resistance include widespread use of Bt corn, high season-long mortality, and two or more pest generations per year (Ostlie, Hutchison and Hellmich). Economic factors also contribute to the development of resistance, since pests are treated as common property, so that growers have little incentives to voluntarily manage resistance (Carlson and Wetzstein).

Resistance management for Bt corn is currently based on a high dose-refuge strategy (Mason et al). This strategy requires growers to plant non-Bt corn acres as a refuge. This refuge generates ECB not exposed to Bt corn that can mate with potential resistant moths emerging from nearby Bt corn. The goal is to produce an overwhelming number of susceptible moths for every resistant moth (at least 500:1) and thus slow the proliferation of resistance genes and prolong the efficacy of Bt (Ostlie, Hutchison, and Hellmich).

Besides the costs of planting these refuge acres, if the pest causes economic damage, the lost yield on refuge acres imposes an additional cost on the grower. Surveys show that though most growers comply with refuge requirements, significant non-compliance exists in some areas. For example, a twelve-state survey found 71% of growers in full compliance, with the remainder showing varying degrees of non-compliance (Hunt and Corley).

The U.S. Environmental Protection Agency (EPA) is concerned that growers are planting too little or no refuge acres. At a series of workshops, the EPA requested expert and public comment on compliance issues and methods such as education, direct subsidy, fines, and refuge insurance and sales incentives (US EPA 1999, 2001). In related research, Mitchell et al. evaluated direct subsidy, fines, and refuge insurance as compliance mechanisms. To address moral hazard problems, monitoring was required for all mechanisms. They found that a direct subsidy or fine program is likely to be more efficient, unless insurance had relatively low administrative costs or lower monitoring costs. However, because their analysis examined the issue primarily from a grower's point of view, they did not derive optimal monitoring conditions or comprehensively describe tradeoffs between the different mechanisms.

Refuge acres for Bt corn are more than just a good idea—they are required by the EPA. Among the conditions for product registration, in January of 2000, the EPA directed registrants selling Bt corn "… to require that growers plant a minimum structured refuge of at least 20 percent non-Bt corn; for Bt corn grown in cotton areas, registrants must ensure that farmers plant at least 50 percent non-Bt corn;" (US EPA 2000).

The purpose of this paper is to find the optimal rebate and subsidy contracts that secure grower compliance. We develop a principal-agent model to derive the optimal contract between the Bt corn registrants (seed companies) and growers under asymmetric information.

Conceptual Framework

To model the Bt corn refuge compliance problem, we develop a principal-agent model. To keep the analysis analytically tractable for this conceptual model, we make several simplifying assumptions to capture the essence of the problem without loss of generality (Laffont and Martimort). Because the EPA makes Bt corn registrants responsible for ensuring compliance, we make the seed company selling Bt corn the principal and the grower the agent.

Grower Returns, Effort, and Preferences

Pest damage causes proportional yield loss (Hennessy; Lichtenberg and Zilberman; Saha, Shumway, and Hannevar). Thus, yield (bu/ac) for conventional corn is $y(1-\lambda)$, where y is potential (pest-free) yield and λ is the proportion of yield lost due to pest damage. Because Bt corn provides essentially complete ECB control and no yield drag has been reported for Bt corn (Graeber, Nafziger and Mies; Minor et al.; Nielsen; Willson), yield for Bt corn is simply y (Mitchell et al.). As a result, per acre returns for a grower planting conventional corn are $\pi_{cv} = py(1 - \lambda) - w$, where p is the price of corn and w is the (non-random) production cost. Per acre returns for a non-complying grower who plants all Bt corn are $\pi_{bt} = py - w - T$, where T is the additional cost per acre for purchasing Bt corn seed (usually identified with the "technology fee"). Returns for a complying grower planting the required proportion of refuge ϕ are $\pi_{\phi} = \phi\pi_{cv} + (1 - \phi)\pi_{bt}$. Finally, assume y and λ are independent (Mitchell et al.; Hyde et al.).

Grower utility from per acre returns is $U(\cdot)$, where $U' > 0$ and $U'' < 0$. For analytical tractability, we assume the grower has a negative-exponential utility function: $U(\pi) = 1 - \exp(-A\pi)$, where A is the Arrow-Pratt coefficient of absolute risk aversion and π is per acre grower returns.

Let C_C denote the grower's unique cost of voluntarily complying with the Bt corn refuge requirement. This C_C is implicitly defined by

$$\mathrm{E}[U(\pi_{\phi} + C_C)] = \mathrm{E}[U(\pi_{bt})],$$

where $\mathrm{E}[\cdot]$ denotes the expectation over both y and λ. The grower's incentive to violate the refuge mandate depends on this compliance cost. If $C_C \leq 0$, the grower voluntarily complies, which is a case of no interest. If $C_C > 0$, Bt corn increases average yield and profit, reduces profit risk, or both, and the grower does not voluntarily comply. The grower exerts costly effort e to comply with the refuge requirement. Without loss of generality, we normalize effort to equal one if the grower complies and zero if he does not comply (Laffont and Martimort). Exerting compliance effort implies a disutility for the agent equal to $C_C(e)$, which we normalize so that $C_C(0) = 0$ and $C_C(1) = C_C$. With negative-exponential utility, $C_C = CE_{bt} - CE_{\phi}$, where CE_i denotes the grower's certainty equivalent for random profit π_i.

Grower Contracts and Constraints

We examine a rebate contract and a subsidy contract. Both can solve the compliance problem, but at different cost to the principal. For the rebate contract, the grower receives a registration form for each bag of Bt corn purchased that the grower submits to the seed company. The form reports grower contact information, as well as the location and amount of Bt corn and associated refuge. By filing this report, the grower receives a per acre rebate R. However, some growers are randomly selected for an audit. Auditors visit the field and determine whether the filed report was correct. If so, the grower still receives the rebate, but if there is a compliance violation, the grower is denied the rebate.

The subsidy contract is similar. Again the grower receives a registration form with each bag of Bt corn purchased and submits the form to the seed company. However, for this contract, registered growers are randomly selected for an audit. If the auditors find no compliance violation, the grower receives a per acre subsidy S, but if there is a violation, the grower is denied the subsidy.

Let α be the probability that the company audits a grower for compliance and assume that auditors correctly identify compliant and noncompliant growers. The probability that a grower receives a rebate or subsidy depends on the grower's compliance effort. With the rebate contract, a complying grower always receives the rebate, but a non-complying grower forfeits the rebate with probability α and receives it with probability $(1 - \alpha)$. With the subsidy contract, a complying grower receives the subsidy with probability α and receives nothing with probability $(1 - \alpha)$.

The primary constraint that the principal faces when designing the rebate or subsidy contract is to create grower incentives to solve the moral hazard problem. The contracts solve the moral hazard problem only if, when subject to the rebate or subsidy contract, the grower prefers to comply and plant Bt corn refuge to cheating and planting all Bt corn. For the rebate contract, the incentive compatibility constraint is:

$$\text{E}[U(\pi_\phi + R)] \geq \alpha\text{E}[U(\pi_{bt})] + (1 - \alpha)\text{E}[U(\pi_{bt} + R)]. \tag{1}$$

For the subsidy contract, the incentive compatibility constraint is:

$$\alpha\text{E}[U(\pi_\phi + S)] + (1 - \alpha)\text{E}[U(\pi_\phi)] \geq \text{E}[U(\pi_{bt})]. \tag{2}$$

Because the grower's payoff is monotonic in α, R, and S, the incentive compatibility constraints will bind for the principal's optimal contract.

Because the grower can always choose not to purchase Bt corn, this possibility becomes a constraint for the principal when designing the rebate or subsidy contract. These constraints ensure that, instead of planting conventional corn, the grower prefers to buy Bt corn and comply with the refuge requirement when subject to the possibility of receiving a rebate or subsidy. The participation constraint for the rebate contract is:

$$\text{E}[U(\pi_\phi + R)] \geq \text{E}[U(\pi_{cv})]. \tag{3}$$

The participation constraint for the subsidy contract is:

$$\alpha\text{E}[U(\pi_\phi + S)] + (1 - \alpha)\text{E}[U(\pi_\phi)] \geq \text{E}[U(\pi_{cv})]. \tag{4}$$

Examining conditions (1) and (3) indicates that as long as the rebate is positive and the grower's expected utility from planting all Bt corn exceeds expected utility for conventional corn, if condition (3) is satisfied, condition (1) will be as well. Comparing conditions (2) and (4) yields the same conclusion—if condition (2) is satisfied, condition (2) is as well.

The Principal's Optimal Contracts

The risk-neutral principal maximizes expected net returns from selling Bt corn, minus the costs of monitoring, paying rebates or subsidies, and the development of ECB resistance. The principal chooses the audit rate α and either the rebate R or subsidy S to pay. We assume that the principal does not choose the technology fee T as part of this contract design. Rather market forces determine the technology fee.[1] Monitoring cost is linear in the audit rate α, so that the total monitoring cost is $k\alpha$, where $k > 0$.

Pest resistance has two values: low and high. High resistance implies that the ECB has developed resistance to Bt corn and the principal suffers a large loss M as a result of lost sales, lawsuits, fines, and similar. Because a low level of resistance is "natural," the cost to the principal in this case is zero. The probability of high or low resistance depends on grower compliance effort. If the grower does not comply, the probability that a low level of resistance occurs is π_0. If the grower complies, the probability that a low level of resistance occurs is π_1, where $\pi_1 > \pi_0$.

For the rebate contract, the principal's expected returns are

$$V_R = T(1 - \phi) - k\alpha - R - (1 - \pi_1)M, \tag{5}$$

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[1] With an endogenous technology fee, the principal always sets T so that the grower's participation constraint binds and the grower receives the reservation payoff, which here is the same as the payoff for conventional corn. Asymmetric information concerning each grower's maximum willingness to pay for Bt corn prevents this result. Though interesting, optimal pricing of Bt corn is peripheral to this paper's focus on the moral hazard problem of Bt corn refuge.

if the grower complies. To derive the optimal contract, the principal maximizes these expected returns, subject to the grower's incentive compatibility constraint and participation constraint. Since only the incentive compatibility constraint binds, solving condition (1) as an equality for R gives (see appendix):

(6) $$R(\alpha) = \ln[(\exp(AC_C) - 1 + \alpha)/\alpha]/A.$$

Substituting this result into the principal's objective yields an unconstrained maximization problem with respect to α. Rearranging the first order condition gives the following quadratic equation in α (see appendix):

(7) $$\alpha^2 - (1 - \exp(AC_C)\alpha + (1 - \exp(AC_C))/kA = 0.$$

The positive root of this equation is the optimal audit rate for the rebate contract, which we denote α_R^*. Evaluating equation (6) at this α_R^* gives the optimal R^*.

For the subsidy contract, the principal maximizes expected returns, subject to the grower's incentive compatibility constraint and participation constraint. In this case, the principal's expected returns if the grower complies are:

(8) $$V_S = T(1 - \phi) - k\alpha - \alpha S - (1 - \pi_1)M.$$

Again, since only the incentive compatibility constraint binds, solving condition (2) as an equality for S gives (see appendix):

(9) $$S(\alpha) = \ln\big(\alpha/(\alpha - 1 + \exp(-AC_C))\big)/A,$$

where EU_i is expected utility when the grower has returns π_i. Substituting this result into the principal's objective yields an unconstrained maximization problem with respect to α. Rearranging the first order condition gives the following implicit equation defining the optimal α (see appendix):

$$(10) \qquad \frac{1-\exp(-AC_C)}{\alpha-1+\exp(-AC_C)} - \ln\left(\frac{\alpha}{\alpha-1+\exp(-AC_C)}\right) - kA = 0\ .$$

We use α_S^* to denote the audit rate implicitly defined by this equation. Evaluating equation (9) at this α_S^* gives the optimal S^*.

For the principal to prefer implementing one of these contracts, the principal's expected returns when the grower complies must equal or exceed expected returns when the grower does not. For both contracts, this condition can be reduced to a lower bound on the cost of resistance M to the principal. To ensure that this condition is satisfied, the government regulator such as the EPA need only threaten to impose a sufficiently large penalty on the principal if resistance develops.

Growers prefer the rebate contract. The incentive compatibility constraints bind for both contracts, and comparing conditions (1) and (2) shows that the lower bound on the grower's expected utility is higher for the rebate contract. The principal prefers the contract that yields greater expected returns. Using the definitions of V_R and V_S, V_R exceeds V_S if $\alpha_R^* k + R^* < \alpha_S^*(k + S^*)$. This condition simply compares the total program costs for both contracts, since with both contracts the principal earns the same income form selling Bt corn and pays the same expected cost for the development of resistance. However, without explicit solutions for α^*, R^* and S^* for both contracts, the principal's payoff for each cannot be determined analytically. Rather, the payoffs must be compared numerically using an empirical model.

Empirical Model

We develop an empirical model to evaluate these contracts. We link ECB larval population and tunneling data from Bt field experiments to a yield loss model developed from Bt corn field trial data. Following published studies, an independent distribution is used for potential yield. Because analytical solutions do not exist for the empirical model, simulation methods are used to obtain results for the economic analysis.

Dry weather (no rainfall, low humidity) during the ECB mating period and excessive rainfall at larval hatch can greatly reduce ECB populations (Mason et al.). Cumulative weather over the season determines corn yield, but these acute events during critical periods for ECB have little impact on yield, so that empirically little correlation exists between potential yield and ECB populations (Showers et al.). Thus we assume potential yield is uncorrelated with the ECB larval population, tunneling, and proportional damage, an assumption consistent with other analyses (Hyde et al.; Mitchell et al.). Similarly, given the paucity of data, we assume that potential yield is uncorrelated with the effects of Bt corn on yield that is not related to ECB control.

ECB Larval Population and Tunneling

We use the model of Mitchell et al. for the unconditional distribution of the ECB larval population and the conditional distribution of stalk tunneling by ECB larvae. A brief summary of model development follows. State average ECB larval population data for Illinois (1943-1996) and Minnesota and Wisconsin (1963-1998) and county data for Boone County, IA; Cuming County, NE; and Hall County, NE (1960-1969) were available from Bullock and Nitsi and Calvin. Since larval populations must be positive, a lognormal distribution for each location was estimated via maximum likelihood. Consistent with other empirical studies (Chiang and Hodson; Chiang et al.; Showers et al.), time trends were insignificant and removed and no significant autocorrelation among the errors existed. Table 1 reports the estimated parameters of the lognormal distribution for each location.

Data from Bt corn field trials conducted in 1997 by academic collaborators in nine states (IA, IL, MD, MN, MO, NE, OH, SD, and WI) were obtained from Monsanto, with most (77%) of the data from IA, IL, and NE. No stalk tunneling occurred in the Bt fields, so only data from non-Bt fields are used for estimation. The average per plant larval population and average stalk tunneling (cm) were reported for 211 non-Bt fields. Since field average tunneling must be non-negative, a conditional lognormal distribution was estimated via maximum likelihood with its mean and standard deviation depending on the ECB larval population. A zero intercept was imposed in all cases, since no tunneling can occur without ECB larvae. Various linear and nonlinear models were evaluated and the best fitting model ($R^2 = 0.822$) had a conditional mean of $a_1 n + a_2 \sqrt{n}$ and a conditional standard deviation of $b_0 + b_1 n$, where n is the ECB larval population per plant. Parameter estimates with standard errors in parentheses are $a_1 = 2.555$ (0.840), $a_2 = 5.654$ (1.002), $b_0 = 3.397$ (0.756), and $b_1 = 1.730$ (0.553).

Yield Loss and Potential Yield

We use the model of Hurley, Mitchell, and Rice for proportional yield loss due to ECB damage. Data from on-farm field trials conducted between 1997-1999 in 22 Iowa counties were used to estimate proportional yield loss conditional on tunneling by second-generation ECB larvae. Bt and non-Bt isoline hybrids were planted side by side. Collected data included machine harvested yield for the Bt and conventional strips and average ECB tunneling in the conventional hybrid. A total of 138 observations were available. Proportional yield loss is calculated as the difference between Bt yield and conventional yield, divided by Bt yield.

A variety of functional forms were estimated for proportional yield loss as a function of average tunneling, including negative exponential, Cobb-Douglas, logarithmic, and combinations of linear and square root terms. A zero intercept was imposed so that Bt and conventional corn had the same expected yield when no tunneling occurred, implying that on average, no Bt corn yield drag exists. Though yield drag has been shown for some transgenic crops (Elmore et al.), our assumption is consistent with empirical findings for Bt corn (Graeber, Nafziger and Mies; Minor et al.; Willson).

As in Mitchell et al., a univariate Cobb-Douglas model gave the best fit: $\lambda = \alpha t^{\beta} + \sigma\varepsilon$, where λ is proportional yield loss, t is ECB tunneling (cm), ε is a standard normal error and α, β, and σ are estimated parameters. Maximum likelihood estimates are $\alpha = 0.0205$ (0.00579), $\beta = 0.581$ (0.123), and $\sigma = 0.0575$ (0.00832), with p-values less than 0.001. Low correlation between tunneling and yield loss results in a low adjusted R-squared (0.169), but is typical with ECB field data (Mitchell et al.; Berry and Campbell).

We use a beta density for the distribution of potential yield, a common assumption for crop yields (Goodwin and Ker). The beta density has four parameters: two shape parameters ν and ω and the minimum and maximum. The mean in each location is the average of the state or county average yield (bu/ac) reported by USDA-NASS (2002) for 1999-2001. Dryland averages are 147.7, 141.7, 134.0, and 154.7 in Illinois, Minnesota, Wisconsin, and Boone County, IA. Irrigated averages are 161.0 and 161.3 in Cuming County, NE and Hall County, NE.

Following published data (Coble, Heifner, and Zuniga; Hennessy, Babcock and Hayes), the coefficient of variation for potential yield is set at 30% for dryland corn and 15% for irrigated corn. Following Babcock, Hart, and Hayes, the minimum potential yield for each location is zero and the maximum is the mean plus two standard deviations. The beta density shape parameters ν and ω consistent with these assumptions are $\nu = 3.542$ and $\omega = 2.125$ for the dryland locations and $\nu = 9.487$ and $\omega = 2.846$ for the irrigated locations.

Grower Returns and Simulation Methods

Per acre grower returns for conventional corn and Bt corn with and without compliance (π_{cv}, π_{bt}, π_{ϕ}) are calculated using the model of grower returns from the conceptual model. To focus on yield risk, we use a non-random price of p = \$2.00/bu and a non-random cost of production w = \$200/ac (Iowa State University Extension). Reflecting current prices, we use a technology fee of T = \$8/ac (Benbrook 2002).

Following Babcock, Choi, and Feinerman, we choose the coefficient of absolute risk aversion A as a percentage of the standard deviation of per acre returns. For each location, the average of the standard deviation of returns for conventional corn and Bt corn with and without compliance was calculated, then A determined for a risk premium that is 20% and 40% of this standard deviation for each location using the method of Babcock, Choi, and Feinerman. Table 2 reports the resulting values of A for each location and risk premium.

The specified model for the relationship between yield loss, ECB tunneling, and the ECB population is a hierarchical model. A hierarchical model expresses a complex process as a series of linked conditional and marginal distributions (Casella and Berger, pp. 162-168). The parameters of one distribution depend on another random variable with its own parameters, and these parameters may also depend on another random variable, and so on, until reaching a final unconditional distribution. For the empirical model here, the first conditional distribution in the hierarchy is loss conditional on tunneling. Tunneling then has a conditional distribution depending on the ECB larval population, and finally the ECB larval population is unconditionally distributed.

Closed form expressions for unconditional distributions and their moments for conditional random variables in the hierarchy commonly do not exist, so that simulation methods are needed (Gelfand and Smith). For this model, the analytical problem arises when trying to derive the unconditional distribution for proportional loss and its moments. As a result, Monte Carlo integration is used to solve integrals numerically (Greene, pp. 192-197). A C++ program used algorithms reported in Press et al. to draw the required random variables. Experimentation found that 50,000 draws from each probability density were sufficient for estimates to stabilize.

Results

Table 2 shows that Bt corn generates a substantial increase in expected profit of $3.15/ac to $12.85/ac for most growers, even with a technology fee of $8/ac. Bt corn slightly increases the standard deviation of profit in the dryland systems and slightly decreases it in the irrigated systems. This possibility of variance increasing or decreasing effects of pest control has been noted by others (Horowitz and Lichtenberg; Pannell; Feder) and demonstrated for Bt corn by Hurley, Mitchell and Rice. The cost of compliance, C_C, ranges from \$0.50/ac to almost \$3/ac with a 20% risk premium. Increasing risk aversion decreases the compliance cost, since it decreases the value of Bt corn in this example.

Table 3 and 4 report the optimal audit rate and rebate or subsidy for each contract. Table 3 assumes a monitoring cost parameter of $k = 2$ and table 4 uses $k = 10$. The optimal audit rate for the rebate contract seems relatively high. Indeed, it even exceeds one in Cuming and Hall counties. However, the rebates are quite small, ranging \$1 to \$2.50 per acre of Bt corn and its associated refuge. However, such a program is likely to be costly, since frequent monitoring is required. Increasing the monitoring cost parameter k to 10 greatly reduces the optimal audit rate, since the cost of audits increases. Increasing k also increases the optimal rebate, since the cheating grower's probability of losing the rebate decreases with the lower audit rate.

The subsidy contract has far more realistic audit rate, ranging 2-15% depending on the location and the level of grower risk aversion. The optimal subsidy ranges around \$20-\$20/ac with the moderate risk premium and \$6 to \$20 with the high risk premium. Increasing the cost parameter k has the same effect as for the rebate contract. Again, the audit rate decreases since audits are more costly, and so the subsidy must increase, since the probability that a complying grower receives a subsidy decreases.

As previously noted, growers prefer the rebate contract because the binding of their incentive compatibility constraint places a higher lower bound on their expected utility. Using the results in tables 3 and 4, the difference in program costs paid by the principal for both contracts can be calculated, and then the principal's preferred contract can be determined. In all cases reported in tables 3 and 4, the principal has greater expected returns with the subsidy contract.

Conclusion

Bt corn resistance management uses a high dose-refuge strategy that requires growers to plant non-Bt corn acres as a refuge (Mason et al.). Besides the added costs of planting these refuge acres, the lost yield on these refuge acres imposes another cost. Surveys show that significant non-compliance exists in some areas (Hunt and Corley). As a result, the U.S. Environmental Protection Agency (EPA) is concerned that growers are planting too few refuge acres. Therefore, among the conditions for product registration, the EPA requires that registrants develop program to ensure that growers comply with Bt corn refuge requirements. Following this lead, we apply principal-agent theory to derive two contracts that use a rebate and a subsidy to address the moral hazard problem.

We develop a conceptual model to illustrate the contracts, and then develop an empirical model to evaluate both contracts. Both contracts can theoretically salve the moral hazard problem by using compliance audits. Auditors randomly visit Bt corn growers and for the two contracts either deny rebates to noncompliant growers or give a subsidy to complaint growers. For the empirical model, we link field data on pest populations from several locations around the Corn Belt with pest damage and yield loss data from Bt corn field trials. Empirical results indicate that seed companies prefer the subsidy contract, since it can achieve compliance with a relatively low audit rate (2-15%) without having to pay substantial subsidies.

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Table 1. Estimated mean and coefficient of variation for per plant European corn borer larval population.

Location[*]	Estimated Mean	Standard Error	Estimated Coefficient of Variation	Standard Error
Illinois	1.199	0.117	0.713	0.085
Minnesota	0.807	0.123	0.940	0.149
Wisconsin	0.551	0.093	1.058	0.177
Boone County	0.845	0.240	0.922	0.276
Cuming County	1.840	0.463	0.811	0.231
Hall County	1.801	0.301	0.531	0.134

[*] State data from Bullock and Nitsi; county data from Calvin.

Table 2. Economic results for per acre grower returns with conventional and B corn with and without compliance.

Location	Illinois	Minnesota	Wisconsin	Boone County	Cuming County	Hall County
Mean Profit						
Conventional	76.67	68.34	55.86	92.63	98.35	98.38
Bt Corn	87.18	75.19	59.80	101.17	113.84	114.44
Compliance	85.08	73.82	59.01	99.46	110.74	111.23
St. Dev. Profit						
Conventional	85.59	82.48	78.27	90.01	51.45	51.33
Bt Corn	88.73	85.13	80.50	92.94	48.52	48.61
Compliance	87.69	84.29	79.82	92.00	48.06	48.12
20% Risk Premium						
CARA[a]	0.004707	0.004896	0.005149	0.004485	0.008332	0.008328
Compliance Cost[b]	1.64	1.00	0.49	1.29	2.87	2.97
40% Risk Premium						
CARA[a]	0.01031	0.01073	0.01128	0.009826	0.01825	0.01824
Compliance Cost[b]	1.07	0.54	0.12	0.78	2.47	2.56

[a] CARA is the coefficient of absolute risk aversion (*A*).

[a] Compliance cost is the per acre cost of complying with Bt corn refuge (C_C).

Table 3. Optimal contract parameters for the rebate and subsidy contracts with audit cost parameter *k* = 2.

Location	Illinois	Minnesota	Wisconsin	Boone County	Cuming County	Hall County
20% Risk Premium						
Rebate Contract						
Audit Rate α^*	0.903	0.705	0.493	0.802	1.193	1.214
Rebate R^*	1.81	1.41	0.99	1.61	2.41	2.45
Subsidy Contract						
Subsidy: α^*	0.061	0.038	0.019	0.047	0.145	0.151
Subsidy: S^*	28.50	27.93	27.22	29.21	21.26	21.27
40% Risk Premium						
Rebate Contract						
Audit Rate α^*	0.727	0.516	0.242	0.622	1.100	1.120
Rebate R^*	1.46	1.04	0.49	1.25	2.25	2.29
Subsidy Contract						
Subsidy: α^*	0.061	0.032	0.007	0.044	0.193	0.200
Subsidy: S^*	19.09	15.21	6.37	18.01	19.75	19.76

Table 4. Optimal contract parameters for the rebate and subsidy contracts with audit cost parameter *k* = 10.

Location	Illinois	Minnesota	Wisconsin	Boone County	Cuming County	Hall County
20% Risk Premium						
Rebate Contract						
Audit Rate $\alpha_R{}^*$	0.402	0.314	0.220	0.357	0.527	0.536
Rebate R^*	4.06	3.16	2.21	3.60	5.39	5.48
Subsidy Contract						
Subsidy: $\alpha_S{}^*$	0.030	0.019	0.010	0.023	0.074	0.077
Subsidy: S^*	62.02	60.75	59.16	63.60	45.88	45.89
40% Risk Premium						
Rebate Contract						
Audit Rate $\alpha_R{}^*$	0.322	0.229	0.108	0.276	0.480	0.488
Rebate R^*	3.27	2.32	1.09	2.80	5.02	5.11
Subsidy Contract						
Subsidy: $\alpha_S{}^*$	0.032	0.016	0.004	0.023	0.104	0.108
Subsidy: S^*	43.33	33.66	13.29	40.42	49.12	49.17

Appendix

Proof of Equation (6)

If the incentive compatibility constraint binds, condition (1) becomes

(A1) $$\mathrm{E}[U(\pi_{\phi}+R)] = \alpha\mathrm{E}[U(\pi_{bt})] + (1-\alpha)\mathrm{E}[U(\pi_{bt}+R)].$$

With negative-exponential utility, $\mathrm{E}[\exp(-A\pi_i)] = 1 - EU_i$. Substitute this definition into equation (A1), multiply by minus one, and rearrange to obtain:

(A2) $$\exp(-AR)(1 - EU_{\phi}) = (1 - EU_{bt}.)(\alpha + (1-\alpha)\exp(-AR))$$

Take the natural logarithm of both sides, divide by $-A$, and substitute in the definition of the certainty equivalent to obtain:

(A3) $$CE_{\phi} - CE_{bt} = -\ln[1 - \alpha + \alpha\exp(AR)]/A.$$

Solving this equation for R gives:

(A4) $$R(\alpha) = [\ln(\exp(AC_c) - 1 + \alpha)/\alpha]/A$$

Proof of Equation (7)

The first order condition for maximizing equation (5) with respect to α is

(A5) $$-k - \partial R/\partial\alpha = 0.$$

From (A4) we get

(A6) $$\partial R/\partial\alpha = \frac{\exp(AC_c) - 1}{A\alpha(\alpha - 1 + \exp(AC_c))}.$$

Substitute this into (A5) and rearrange to obtain

(A7) $$\alpha^2 - \alpha(1 - \exp(AC_c)) + (1 - \exp(AC_c))/kA = 0.$$

Proof of Equation (9)

If the incentive compatibility constraint binds, condition (2) becomes

(A8) $$\mathrm{E}[(1 - \alpha)U(\pi_{\phi}) + \alpha U(\pi_{\phi} + S)] = \mathrm{E}[U(\pi_{Bt})].$$

Substitute $\mathrm{E}[\exp(-A\pi_i)] = 1 - EU_i$ into equation (A8), multiply by minus one, add one, and rearrange to obtain:

(A9) $$(1 - \alpha + \alpha\exp(-AS))(1 - EU_{\phi}) = 1 - EU_{bt}.$$

Take the natural logarithm of both sides, divide by $-A$, and substitute in the definition of the certainty equivalent to obtain:

(A9) $$CE_{\phi} - CE_{bt} = \ln(1 - \alpha + \alpha\exp(-AS))/A.$$

Solving this equation for S gives:

(A10) $$S(\alpha) = [\ln(\alpha / (\alpha - 1 + \exp(-AC_c)))]/A.$$

Proof of Equation 10

The first order condition for maximizing equation (8) with respect to α is

(A11) $$- k - S - \alpha(\partial S / \partial \alpha) = 0.$$

From (A10) we get

(A12) $$\partial S / \partial \alpha = \frac{\exp(AC_c) - 1}{A\alpha(\alpha - 1 + \exp(AC_c)} .$$

Substitute this result and equation (9) into (A11) to obtain:

(A13) $$- k - \left[\ln\left(\frac{\alpha}{\alpha - 1 + \exp(-AC_C)} \right) / A \right] - \frac{\exp(AC_c) - 1}{A(\alpha - 1 + \exp(AC_c)} = 0 .$$

Rearrange this equation to obtain an implicit equation for α:

(A14) $$\frac{1 - \exp(-AC_C)}{\alpha - 1 + \exp(-AC_C)} - \ln\left(\frac{\alpha}{\alpha - 1 + \exp(-AC_C)} \right) - kA = 0 .$$