A Principal-Agent Model for Regional Pest Control Adoption

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Abstract

Investigating the underlying producer characteristics associated with regional pest control adoption revealed an interesting proposition. Early adopting producers of firm-specific techniques with characteristics including higher education, more specialized operations, and larger sized business units are dissatisfied with a regional pest control technique. This study provides an explanation of the proposition based on a principal-agent model. Empirical support for the proposition is also presented by developing a multinomial logit model for predicting producers' dissatisfaction with boll weevil eradication.

Key Words: regional pest control, principal-agent model, proposition, firm-specific, industry-specific.

Regional pest control may mitigate externalities associated with mobile pests and pesticide drift with the resulting potential enhancement of producers' net returns. Special cases of regional pest control are successful pest eradication programs. In particular, focusing on the cotton boll weevil eradication (BWE) program, Ahouissoussi *et al.*, Carlson *et al.*, and Carlson and Suguiyama provided evidence of success by determining eradication significantly increased producers' net returns.

Previous literature assumed, if a program increased net returns, producers would be satisfied with this program and support its adoption (Burrows; Rook and Carlson). However, conventional theories describing technology adoption in agriculture have addressed additional adoption constraints associated with riskiness, divisibility, substitutability, and availability. In reality, even given producer subsidies for dealing with these constraints, there still appears reluctance for readily supporting BWE on the part of a significant number of producers. This reluctance has hampered the Animal and Plant Health Inspection Service (APHIS) efforts in expanding the program westward from the Carolinas.

Expansion requires a producer referendum with two-thirds of the votes supporting BWE. Each successful referendum obliges all cotton producers participation in BWE and delegates APHIS authority for uniform eradication activities on all cotton grown within a prescribed area. Generally, the first referendum falls short of the necessary two-thirds approval; resulting in a great deal of effort on the part of APHIS for insuring the second referendum garnishes the necessary support for passage. Producers resisting change and low voter participation are given by APHIS as possible explanations for weak first referendum results.

Investigating the underlying producer characteristics associated with this resistance revealed an interesting proposition. Early adopting producers of new techniques with characteristics summarized by Rogers including higher education, more specialized operations, and larger sized

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business units were dissatisfied with BWE. An explanation of the proposition is offered, in this study, based on a principal-agent model. Empirical support for the proposition is also presented by developing a multinomial logit model for predicting producers' dissatisfaction with BWE. Logit results are then interpreted in light of the principal-agent model. This interpretation indicates a different set of producer characteristics are associated with resistant producers for industry-specific technologies including BWE versus resistant producers for firm-specific technologies say a new crop variety. The implication of these results are important as BWE expands further west. Knowledge of the characteristics associated with dissatisfied producers can be used by APHIS personnel in the design of information materials and incentives for supporting BWE.

Principal-Agent Model

The principal, APHIS, is interested in inducing a particular response from agents, producers. The principal's problem is designing an incentive payment for this inducement. Let R_i represent the reduction of pests, say boll weevils, from a crop associated with an agent of type i. For convenience suppose there are only two types of agents. A high-cost agent with a cost function denoted as $c_2(R)$ and a low-cost agent denoted as $c_1(R)$, where $c_2(R) > c_1(R)$. These costs are an agent's anticipated loss associated with the adoption of a regional pest control program. They represent a producer's loss in economic rent by switching from individual firm control of pest management towards regional control. This loss is the total per acre cost of regional pest control, $r_i(R)$, minus the potential gain in rents as measured by potential increases in yields and reduction in inputs from this switch, n_i, conditional on a given level of R

$$c_i(R) = r_i(R) - n_i(\Delta Y_i, \Delta A_i, \Delta B_i, \Delta O_i, \Delta N_i \mid R), \quad (1)$$

where Δ denotes change in the variable magnitude resulting with administration of regional pest control, and Y_i represents crop yield per acre, A_i represents planted acreage in acres, B_i denotes producers' own per acre cost of controlling the particular pest considered for regional control, O_i and N_i represent other insect control costs in dollars per acre and non-pest control costs per acre, respectively. For those producers where $c_i(R) < 0$, indicating regional control costs, r_i, do not completely offset the positive rents, n_i, an incentive payment is not required for their support of regional control which negates the principal-agent problem. However, the problems encountered with producer referendums indicate $c_i(R) > 0$ for a significant number and type of producers. An incentive scheme is then required for producer adoption.

These potential gain in rents from regional control, n_i, will vary across producers. Producers' gain in rents from regional control will be relatively less for those producers experiencing high economic rents without regional control. Early adopting producers of firm-specific pest-control technologies may experience temporary higher rents without regional control if these rents are not totally dissipated by the costly early adoption and there is a lag in imitating the technology (Tirole). Thus, for these early adopting producers the potential gains from regional pest control may be small resulting in a higher cost of supporting regional pest control. The high cost agents, $c_2(R)$, are associated with these early adopting producers.

Let s be the producer payment (subsidy) from APHIS required for producers supporting regional control. Then agent i's utility function is of the form $s - c_i(R)$. Generally, the principal has limited information on the type of cost functions, so a probability of π_i is associated with a type i cost function. The principal must design an incentive scheme that does well on average whatever type of agent is involved. Following Varian along with normalizing the value of a per unit reduction in pest control, the principal's optimization problem is

$$\max_{R_1, R_2, s} \pi_1 R_1 + \pi_2 R_2 - s,$$

such that

$$\begin{aligned} s - c_1(R_1) &\geq 0, \\ s - c_2(R_2) &\geq 0, \\ c_1(R_1) &\leq c_1(R_2), \\ c_2(R_2) &\leq c_2(R_1). \end{aligned}$$

The first two constraints are the participation constraints. If the payment s does not cover the switching costs, then the agent will not support the regional program. The last two constraints are the incentive compatibility constraints. The principal must choose an incentive scheme where there is no benefit for an agent in having an alternative level of pest reduction than the one preferred by the principal.

The optimal actions of the principal may be determined by first considering the two incentive compatibility constraints along with the assumption $c_2(R) > c_1(R)$ for all R. This yields

$$c_1(R_1) \leq c_1(R_2) < c_2(R_2),$$
$$c_2(R_2) \leq c_2(R_1) > c_1(R_1),$$

which imply $c_1(R_1) \leq c_2(R_2)$. Given both participation constraints, the principal wants s as small as possible which corresponds with $s = c_2(R_2)$. For 100 percent agent support of regional control the early adopting producers receive payments that just makes them indifferent between supporting regional control or not. Whereas, the other producers potentially receive a surplus.

Generally, establishment of a mandatory regional control program does not require 100 percent producer support. For example, establishment of a BWE program requires support of only two-thirds of voting producers within a region. Thus, the set of constraints requiring all agents' willing participation may be relaxed. The principal may then reduce the subsidy s and still accomplish the objective of establishing regional control. However, this results in a subset of participation constraints not being satisfied, implying some agents will be dissatisfied with regional control. An example is the BWE program where in many cases second referendums are required. Specifically, in terms of the model, as s is reduced towards $c_1(R_1)$ the high-cost agents' participation constraints are not satisfied, $s - c_2(R_2) < 0$, and thus they will no longer have an incentive for supporting regional control. The association of early adopting producers with high-cost agents implies the following proposition:

> **Proposition 1.** Producers with early technology adoption characteristics will generally be dissatisfied with regional pest control programs.

Empirical support of this proposition is provided by investigating the characteristics of cotton producers who are dissatisfied with BWE.

Empirical Application

Efforts for boosting support for BWE involve a subsidy s in the form of offsetting producer BWE program costs by requiring producer payments of only 70 percent of total program costs. Faced with this subsidy, cotton producers ascertain their satisfaction, indifference, or dissatisfaction with the proposed BWE program. Let y_{ij} be a binary variable for producer i, i = 1, ... T, that takes the value one if the *jth* satisfaction level, j = 1, 2, 3, is chosen and zero otherwise. Let $P_{ij} = \Pr(y_{ij} = 1)$. Then

$$\sum_{j=1}^{3} y_{ij} = \sum_{j=1}^{3} P_{ij} = 1.$$

Assume that producers maximize utility expressed as

$$u_{ij} = \bar{u}_i + e_{ij} = X_i'\beta_j + e_{ij},$$

where X_i is a vector of variables representing the attributes of the *ith* producer, β_j is a vector of unknown parameters which are alternative specific, and e_{ij} is a random disturbance reflecting unobserved attributes of the satisfaction choice. With β_j alternative specific the explanatory vector has differential impacts upon the odds of choosing one alternative over another. Assuming that e_{ij} are independent random variables with a Weibull distribution, then the probability of producer i choosing satisfaction level j is

$$P_{ij} = \frac{\exp(X_i'\beta_j)}{\sum_{j=1}^{3} \exp(X_i'\beta_j)},$$

This is a general form of the logistic distribution function (McFadden). The logarithm of the odds of choosing satisfaction level j rather than alternative level k, (j, k = 1, 2, 3) is

$$\ln \frac{P_{ij}}{P_{ik}} = X_i'(\beta_j - \beta_k).$$

Normalizing on β_k, by setting $\beta_k = 0$, uniquely determines the selection probabilities.

Assume producer satisfaction levels and associated probability of selection are influenced by producers' expected change in rents, $c_i(R_i^*)$, with and without BWE and characteristics of an early adopting producer. The term R_i^* denotes the level of pest reduction by producer of type i required for eradication. This $c_i(R_i^*)$ is represented by (1) where the crop under consideration is cotton measured in pounds of lint per acre and B_i now denotes producers' own per acre cost of cotton boll weevil control. For econometric analysis, the subsidy, s, and total per acre cost of BWE, r, remain constant over the time period considered, so they will not influence producer satisfaction levels. Also, it is assumed that ΔN_i is measured by the management decision unit dimensions Y_{it}, A_{it}, B_{it}, and O_{it}.

Setting satisfaction level monotonic with the real numbers 1, 2, and 3, then it is anticipated that producers experiencing a positive change in yield and planted acreage would have a higher satisfaction level and thus an associated positive coefficient. Whereas, a positive change in boll weevil and other insect control would be associated with a negative coefficient. Assuming large acreage producers benefit proportionately more from BWE and producers with relatively higher pesticide costs, both for boll weevil and other pests, would favor BWE, then a positive sign is anticipated on the coefficients associated with A_{it}, B_{it}, and O_{it}. The sign associated with yield, Y_{it}, is indeterminate. The BWE satisfaction level of a relatively high yield producer depends on the input mix.

Characteristics of early adopting producers are measured by producer's age, AGE_i; educational level, ED_i; percentage of producer's income coming from farming, INC_i; and number of years growing cotton, YR_i. Given Proposition 1, negative coefficients associated with education and percentage income from farming are anticipated. Percentage income from farming is associated with larger sized business units and less diversification, two early adopting characteristics noted by Putler and Zilberman, Rahm and Huffman, and Rogers. Although Rogers concluded earlier adopters are not different from later adopters in age, Batte *et al.* found a significant negative relation with producers adoption of computers. This negative relation may be justified by the shorter time horizon older producers have for reaping the long run benefits associated with programs such as BWE. For years growing cotton, YR_{it}, the sign is indeterminate (Dinar and Yaron). Producers may have remained in cotton production for a long period because they are early adopters or because of inertia behavior.

In summary, X_i is a vector of the following explanatory variables employed in a multinomial logit model and estimated by the maximum likelihood method

$$X_i = (\text{constant}, \underset{(+)}{\Delta Y_{it}}, \underset{(+)}{\Delta A_{it}}, \underset{(-)}{\Delta B_{it}}, \underset{(-)}{\Delta O_{it}}, \underset{(?)}{Y_{it}}, \underset{(+)}{A_{it}}, \underset{(+)}{B_{it}},$$

$$\underset{(+)}{O_{it}}, \underset{(-)}{Age_{it}}, \underset{(-)}{ED_{it}}, \underset{(-)}{INC_{it}}, \underset{(?)}{YR_{it}}),$$

with the anticipated signs in parentheses based on Proposition 1.

Data

Data were obtained on Georgia cotton production practices detailing yields, acreage, and insecticide applications before and after the initiation of the BWE program along with data on the characteristics of early adopting producers. Telephone interviews spanning a five year period from 1986 through 1990 were used for data collection. For all of Georgia, except the northwestern corner, after the first BWE referendum failed the second referendum passed in 1986. The BWE program was then started in 1987 with full implementation by 1988. By 1990 the boll weevil populations were severely depressed. Cases were reported where prior populations levels of over 50 million boll weevils per 1000 acres resulted in only three weevils being reported on the same acreage in 1990 (Lambert).

In the four survey years after 1986 producers in each year were asked if they were satisfied with BWE, not satisfied, or indifferent. These yearly satisfaction levels constitute the y_{ij} variable. As hypothesized in the theoretical section, changes in these satisfaction levels are influenced by changes in yield, acreage, boll weevil control costs, and other insect control costs. These changes in determinants of net return are defined as yearly deviations from year 1986. Year 1986 is pre-BWE and serves as a benchmark year. For example, each year following 1986, the change in yield, ΔY_t, variable consists of yield in that particular year minus yield in the benchmark year. Similar calculations were employed for determining changes in acreage, boll weevil control costs, and other insect control costs for each of the four years.

Results

The results from the multinomial logit model based on 92 complete observations are reported in table 1. The likelihood ratio test indicates the model was significant at the 0.01 level and the pseudo-R^2 of 0.37 is within the range typical for logit models. Percentage of correct predictions is 84 percent which further supports the reliability of the model.

Two coefficients significant at the five percent level are opposite from the anticipated sign. These coefficients are associated with the variables Change in Boll Weevil Cost and Boll Weevil Cost. Considering first the Change in Boll Weevil Cost variable, the significant positive sign indicates that producers are not relating a decline in their boll weevil costs with an increase in BWE program

Table 1. Estimates of Log Odds of Producer Satisfaction With BWE[a]

Variable	Anticipated Sign	Indifferent versus Unsatisfied	Satisfied versus Unsatisfied	Satisfied versus Indifferent
Constant		9.585 (0.78)	25.174 (2.43)**	15.590 (1.86)*
Change				
Yield	+	0.013 (1.93)*	0.016 (2.60)***	0.003 (0.83)
Acreage	+	-0.020 (-1.18)	-0.018 (-1.50)	0.001 (0.09)
Boll Weevil Cost	-	1.429 (1.87)*	1.731 (2.52)**	0.301 (0.70)
Other Insect Cost	-	-1.258 (-2.12)**	-1.621 (-2.90)***	-0.363 (-1.24)
Yield	?	-0.012 (-1.85)*	-0.014 (-2.42)**	-0.002 (-0.59)
Acreage	+	0.016 (1.49)	0.022 (2.35)**	0.006 (0.86)
Boll Weevil Cost	+	-1.098 (-1.65)*	-1.418 (-2.37)**	-0.320 (-0.87)
Other Insect Cost	+	1.210 (2.00)**	1.647 (2.91)***	0.437 (1.45)
Age	-	-0.369 (-1.71)*	-0.624 (-3.10)***	-0.255 (-2.16)**
Education[b]	-	-1.566 (-1.28)	-2.899 (-2.68)***	-1.333 (-1.67)*

Table 1. Continued

Variable	Anticipated Sign	Indifferent versus Unsatisfied	Satisfied versus Unsatisfied	Satisfied versus Indifferent
Farm Income[c]	-	-1.378 (-0.70)	-3.456 (-2.08)**	-2.077 (-1.43)
Years in Cotton	?	0.500 (1.87)*	0.791 (3.12)***	0.291 (1.99)**
Log likelihood		-37.358		
Log likelihood restricted		-59.361		
Model chi-square		44.00***		
Pseudo R-square		0.37		
Percent correctly classified	84.0			

[a]Asymptotic t-ratios in parentheses. A single, double, and triple asterisk indicates significance at the 0.10, 0.05, 0.01 level, respectively.
[b]Education levels were coded as 1 if completed 8*th* or less, 2 if had some high school, 3 if completed high school, 4 had some college, 5 if completed college, and 6 had some type of post graduate education.
[c]Farm income levels are 1 if 10 percent or less of income is from the farm, 2 between 11 and 25 percent, 3 between 26 and 75, and 4 if over 76.

satisfaction. Instead as their boll weevil costs rise they might perceive greater importance of BWE and thus increase their support. The unanticipated sign on Boll Weevil Cost may be investigated by considering the characteristics or profile of a producer who is dissatisfied with BWE. Such a dissatisfied producer generally conforms with the following profile: Full time producer who is older, highly educated, recently entered cotton production, and who intensively manages a low level of cotton acreage by following a sterile field philosophy. This dissatisfied producer also experienced a decline in the change in yield and boll weevil costs and an increase in the change in other insect costs. Sterile field implies a relatively high level of boll weevil control costs resulting from insecticide applications starting early in the growing season for the control of boll weevils. Beneficial insects are then reduced which no longer mitigates pest infestations. Continued insecticide applications are thus required throughout the remainder of a season.

This profile is generally characteristic of an early adopting producer who may have recently discovered potential economic rents in cotton production. The producer has developed a management practice that effectively controls pests resulting in high yielding cotton. This management practice may require intensive management accounting for the low acreage or the producer may be limiting acreage initially until these potential economic rents are confirmed.

Further evidence supporting this link between dissatisfaction with BWE and early adoption is provided by the partial derivatives associated with the satisfied versus dissatisfied estimates, table 2. The derivatives for education and percent of farm income are approximately double in magnitude compared with the other derivatives. This indicates the strong influence these early adoption variables exert on the probability of an dissatisfied producer.

Table 2. Estimates of Percent Change in Asymptotic Probabilities[a]

Variable	Mean	Indifferent versus Unsatisfied	Satisfied versus Unsatisfied	Satisfied versus Indifferent
Change				
Yield	139.00	0.173%	0.007%	0.007%
Acreage	29.60	-0.261	-0.008	0.002
Boll Weevil Cost	1.75	19.012	0.782	0.678
Other Insect Cost	16.24	-16.773	-0.732	-0.816
Yield	435.93	-0.155	-0.006	-0.004
Acreage	221.95	0.209	0.010	0.014
Boll Weevil Cost	8.46	-14.602	-0.640	-0.719
Other Insect Cost	31.00	16.086	0.744	0.984
Age	44.45	-4.903	-0.282	-0.573
Education[b]	3.85	-20.830	-1.309	-2.998
Farm Income[c]	3.60	-18.331	-1.561	-4.672
Years in Cotton	19.51	6.649	0.357	0.655

[a]Evaluated at the mean value of the variables, this is the partial derivative of the logit model (Maddala, p. 23).
[b]Education levels were coded as 1 if completed *8th* or less, 2 if had some high school, 3 if completed high school, 4 had some college, 5 if completed college, and 6 had some type of post graduate education.
[c]Farm income levels are 1 if 10 percent or less of income is from the farm, 2 between 11 and 25 percent, 3 between 26 and 75, and 4 if over 76.

BWE is an industry program within a region where the technology from the start impacts all producers not just producers who are generally early adopting. Thus, there is no incentive on the part of early adopting producers in seizing a scarce opportunity for investing. For technologies that are firm-specific, the option of waiting will expire because some competitor will seize the opportunity. In this case, an early adopting producer will invest as soon as the expected present value crosses zero.

In contrast, for an early adopting producer waiting has a positive value for an industry-specific technology including BWE. Early adopting producers which are reluctant in supporting BWE may have invested considerable effort in determining the least cost combination of inputs for a given level of yield. This least cost combination would require working out the complex matrix of inputs for effective multiple pest control and the mechanisms for addressing any changes in pest dynamics. BWE, by removing one dimension in this decision matrix, has the potential of reducing this complexity. For example, cotton producers reported only four pesticide applications in 1992 and some fields were never treated while in 1986 the average number of applications for just boll weevil numbered approximately 12 (Ahouissoussi *et al.*; McPherson and Douce). This reduction in application number diminishes the complexity of cotton management by restricting the number of application decisions that a producer must make. Thus, the competitive edge that an early adopting producer may have is narrowed with application restrictions imposed by BWE. This narrowing implies that early adopting producers may find positive value in not supporting BWE.

Considering supporters of BWE, results indicate that part-time producers with limited education are the dominant characteristics. Producers with these characteristics see BWE as an avenue for reducing their responsibility in making complex management decisions. This shifting of decisions may offset producer constraints associated with lack of education and limited time for farm management.

Implications

This analysis suggests a fundamental difference in the type of producer who will early adopt industry versus firm specific technologies. For industry-specific technologies including regional pest control such as BWE, producers with early adopting characteristics for firm specific technologies may delay their support of the technology. The option of waiting has positive value. Whereas, for firm-specific technologies this positive option value is diminished by the potential of the option expiring when competitors adopt the technology.

The differential impact of these technologies on the characteristics of dissatisfied producers has direct implications on the incentive structure required for producer support of industry-specific technologies. Considering BWE, APHIS has used research for garnishing BWE support which suggests the expected present value of BWE is positive. If the BWE program were a firm-specific technology this would have potentially a major influence on adoption. Early adopting producers would provide the impetus for overall industry adoption. However, the trigger for dissatisfied producers' adoption of an industry-specific technology requires a higher rate. APHIS is faced with the problem that producers who generally resist change are the supporters of BWE. Thus, industry-specific technologies not only require additional efforts in overcoming this producer inertia behavior but also does not have the impetus for overall adoption as does the firm-specific technology. A possible solution is the increase in subsidy from the current 30 percent of total program costs. However, this involves an increase in direct federal and state funding for BWE. Alternatively, APHIS is significantly improving its methods of producer communication on the economic benefits of BWE. Such efforts may have limited impact on BWE referendums given the characteristics of dissatisfied producers.

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