IMPLICATIONS OF BT COTTON ADOPTION FOR PEST CONTROL THRESHOLDS

by

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STATEMENT BY AUTHOR

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Sincerely,

Ricardo Eugenio Pochat

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CHAPTER I: INTRODUCTION AND LITERATURE REVIEW

The present study is focused on Bt cotton adoption and Threshold Models. What are threshold models, what are they used for and when to use them?

This chapter will explain Bt cotton, and its uses, as well as provide a brief literature review of past studies related to this one. Chapter II talks about threshold models in detail, while Chapter III refers to hypothesis testing.

1.1 Bt Cotton History

Starting in 1996, transgenic cotton - B.t. Cotton- became commercially available to farmers after almost a decade of research and testing. B.t. cotton represents a breakthrough in pest management developed by Monsanto scientists. A gene from Bacillus thuringiensis – hence the nickname B.t. – was inserted into cotton plants to create a caterpillar resistant variety. Cotton plants with the gene produce a toxic protein, which kills caterpillars when they eat it. . The toxin produced by B.t. cotton is harmless to most other organisms. This toxin is produced throughout the growing season, as an alternative to traditional pest management that relies heavily on insecticide sprays; B.t. cotton has proved very efficient in controlling the pink bollworm, cotton bollworm, and tobacco budworm, which can cause major damage in cotton crops. In 1995, the year before Bt cotton became available, over 60% of U.S. cotton acreage was treated for these pests at a cost of $373 million. Growers treating for cotton bollworm and tobacco budworm averaged four applications per treated acre, while growers treating for pink bollworm averaged 3.3 applications. These three pests still reduced U.S. cotton yields by 4% in 1995. Bt cotton represents an increasing share of upland cotton area. The rate of adoption of an acreage basis was 50 percent in 2003 compared with 15 percent in 1996.

1.2 Cotton in the US

The U.S. is the leading cotton producing nation in the world. It has about 1/6 of world's cotton area. US yield per acre is significantly higher than world average so that U.S. share of total output is about 1/5. The U.S. share of total world trade is about 1/4 - 1/3 with substantial annual fluctuations. In 1998 for example, the significant abandonment of planted acres in the U.S. caused a drop in the share.

Virtually all upland cotton production takes place in the 16 Cotton Belt States: Alabama, Arizona, Arkansas, California, Florida, Georgia, Louisiana, Mississippi, Missouri, New Mexico, North Carolina, Oklahoma, South Carolina, Tennessee, Texas and Virginia. The top five states ranked by importance - TX, GA, MS, AR, and NC – accounted for more than 2/3 of the 2001 acreage. Average yields vary considerably between states.

1.3 Literature Review

The final goal of this study is to examine the impact that Bt cotton adoption has on pest control thresholds. Therefore, this review concentrates on the implication that Bt cotton adoption has on pesticide use and yields at an aggregate level. Estimation of this function is important since it allows examining what factors influence the spread of this technology.

1.3.1 Bt cotton adoption's implication on pesticide use and cotton yield

1.3.1.1 In the United States

Marra, et al. (2002) focuses on the use of transgenic crops being rapidly adopted in the United States and few other countries. Some general implications drawn from their analysis are: (1) growing transgenic cotton is likely to result in reduced pesticide use in most years and is likely to be profitable in most years in most U.S. states in the Cotton Belt, (2) Bt corn will provide a small but significant yield increase in most years across the U.S. Corn Belt, and in some years and some places the increase will be substantial, and (3) although there is some evidence of a small yield loss in the Roundup Ready soybean varieties, in most years and locations savings in pesticide costs and, possibly, tillage costs will more than offset the lost revenue from the yield discrepancy. This thesis contributes to Marra's et al. work for this study is done at the aggregate level across the US cotton belt, for more number of years, which lead to additional implications.

1.3.1.2 In China

There is not yet enough evidence to generalize Marra's et al. few conclusions to other countries, although Huang et al. (2002) whose overall goal research was to reexamine findings of earlier efforts that analyzed the effects of Bt cotton adoption in pesticide use, yields and farmers' health due to the alleged reduced pesticide use after Bt is adopted. Huang, J. et al. use data in China from 1999 with two follow-up surveys conducted in 2000 and 2001. Their survey data on yields and econometric analyses indicated that the adoption of Bt cotton continued to increase output per hectare in 2000 and 2001 in China and, that the yield gains extended to all provinces in their sample. More importantly, Bt cotton farmers also increased their incomes by reducing their use of pesticides and labor inputs.

Finally, survey data shows that Bt cotton continues to have positive environmental impacts by reducing pesticide use. Additionally, they provide evidence that farmers have fewer health problems because of reduced pesticide use. Rising yields and expanding area has begun to push cotton prices down, however Huang's at al. find that the total cost per hectare of producing Bt cotton was much less than that for non-Bt cotton in 1999 and 2001, but slightly higher in 2000, mainly due to higher fertilizer inputs. They found that revenues for Bt cotton were higher than revenues for non-Bt cotton due to higher yields obtained by Bt cotton, assuming identical prices for Bt and non-Bt cotton. After deducting total production costs from output revenues, net income from producing

Bt cotton varieties was higher than for non-Bt varieties. In China, because pesticides are primarily applied with small backpack sprayers that are either hand-pumped or have a small engine, and because farmers typically do not use any protective clothing, applying pesticides is a hazardous task—farmers almost always end up completely covered with pesticides.

Huang's et al. approach implies pesticide use and yield of both Bt cotton and non-Bt cotton simultaneously depend on a number of factors (such as geographic and climate conditions, extent of pest density, farmers' characteristics and production inputs). They empirically estimate a pesticide demand function and use a production function approach to estimate the impact of Bt cotton on crop productivity. In the production function approach, they attempt to determine the value and impact on cotton production of two different types of variables: (a) damage abatement inputs, such as pesticide use and/or host plant resistant varieties including the Bt variety; and (b) conventional inputs, such as fertilizers and labor.

The results obtained by Huang et al., suggest that Bt cotton is effective in keeping yields higher than they would have been without Bt adoption. Yields for Bt cotton users are about 5% to 10% higher than those for non-Bt cotton users. When other inputs, human capital variables, time- and location-specific variables, and other factors are accounted for, Bt cotton users get an 8.3% increase in yields in the Cobb-Douglas function and 9.6% in the damage control function.

The adoption of Bt cotton is also associated with a 55% decrease in pesticide use for the entire sample between 1999 and 2001. Reduction rates vary among provinces and range from 20-50% in the lower reach of the Yangtze River Basin to 70-80% in the North China cotton production region. Based on their findings, the hypothesis that Bt cotton does not reduce pesticide use is firmly rejected.

The additional marginal income received from using an additional unit of pesticide, that is to say that the marginal value product (MVP) of pesticides shifts in so that the amount of pesticide use that makes the MVP of pesticides equal to its price is greatly reduced.

1.3.1.3 In India

Qaim and Zilberman (2003) examined results on-farm field trials carried out with Bt cotton in different states of India. They found out that the technology substantially reduces pest damage and increases yields.

The yield gains are much higher than what has been reported for other countries where genetically modified crops were used mostly to replace and enhance chemical pest control. In many developing countries, small-scale farmers suffer big pest-related yield losses because of technical and economic constraints that limit their use of conventional insecticides. Pest-resistant genetically modified crops can contribute to increased yields and agricultural growth in those situations, as the case of Bt cotton in India demonstrates.

Qaim and Zilberman maintain that the limited experience with GM crops so far is insufficient to make broad generalizations about their impacts. Qaim and Zilberman use the example of Bt cotton in India to suggest that currently existing GM crops can have significant yield effects that are most likely to occur in the developing world, especially in the tropics and subtropics.

Bt cotton contains the gene for Cry1Ac, which provides a fairly high degree of resistance to the American bollworm (*Helicoverpa armigera*), the spotted bollworm (*Earias vittella*), and the pink bollworm (*Pectinophora gossypiella*), all of which are major insect pests in India. The first contained field trials with Bt hybrids in India were conducted in 1997. In subsequent years, field tests were extended to collect agronomic data and information for bio- and food-safety evaluation. In 2002, Bt cotton technology was commercially approved, and farmers have started to adopt the new hybrids.

A total of 157 farms constitute their database. On average, Bt hybrids were sprayed against bollworms three times less often than were non-Bt counterparts and popular checks. Individual bollworm control applications were still carried out, because, especially for *H. armigera*, the Cry1Ac protein does not cause 100% mortality and toxin production decreases in aging plants.

There was no significant difference in the number of sprays against sucking pests such as aphids (*Aphis gossypii*), jassids (*Amrasca bigutulla*), and whitefly (*Bemisia tabaci*). Bt does not provide resistance to these insect species. Insecticide amounts on Bt plots were reduced by almost 70%, both in terms of commercial products and active ingredients. Average yields of Bt hybrids exceeded those of non-Bt counterparts and popular checks by 80% and 87%, respectively.

Under Indian conditions, bollworms have a high destructive capacity that is not well-controlled in conventional cotton. On average, pest damage was about 60% on the conventional trial plots in 2001. This result is consistent with earlier studies by entomologists in India, who found that average pest-related losses are 50 to 60%. In the United States and China, estimated losses in conventional cotton due to insect pests account for only 12% and 15%, respectively, because of lower pest pressure and higher adoption of pesticides. This explains why yield effects of Bt technology are smaller in those countries.

Qaim and Zilberman found that the marginal value product of conventional insecticide applications was lower when Bt cotton was planted than when conventional varieties were planted. This result is consistent with those from China cited earlier and will prove important in my theoretical analysis in later chapters.

1.3.1.4 Adoption Studies

Studies of adoption behavior emphasize factors that affect if when a particular individual will begin using an innovation (Sunding and Zilberman 2000). While adoption studies may use a discrete choice model or a continuous variable model to depict the extent of adoption (Sunding and Zilberman 2000), most authors restrict the definition of adoption to refer only to a consumer's or producer's choice to adopt or not to adopt a certain technology. Most adoption studies therefore employ discrete choice models, such as the probit or logit functions, estimate the adoption decision.

The data used in adoption studies often originates from cross-sectional surveys of individual farmers throughout a country or in specific regions. The Agricultural Resource Management Study (ARMS), a set of national surveys developed by the Economic Research Service (ERS) and the National Agricultural Statistics Service (NASS) of the USDA is the main source of nation-wide farm-level information concerning the financial conditions of production agriculture. Fernandez –Cornejo and McBride (2000) utilize data taken from the ARMS survey to estimate probit models of farmers' adoption of several genetically modified crops, including herbicide tolerant soybeans and cotton, and Bt cotton. To explain adoption they considered farm size, operator education and experience, target pests for insecticide use, seed price, debt-to –assets ratios, use of marketing or production contracts, irrigation practices, crop price, use of consultants, and pest pressure. They do not include a discussion of the statistical significance of these variables included in the adoption decision portion of their model.

Another large-scale study of technology adoption at the farm level is the Areas Study Project, also sponsored by the USDA Economic Research Service (Caswell et al. 2001). This study was undertaken to characterize the extent of adoption of nutrient, pest, soil, and water management practices and to assess the factors that effect adoption of these practices. Data used in this study consists of responses to questionnaires designed by the NASS concerning farm operators' use of cropping systems, agricultural production technologies, and chemicals at both the field and whole-farm level in twelve US watershed areas from the years 1991-1993.

The authors of this study identified a core set of variables that they claim are most often cited in the literature as important determinants of the adoption decision. This core set of variables includes: (1) human capital variables, such as the farmer's education level and years of experience (used as proxies to a farmer's ability to acquire and effectively use information about new agricultural production technologies); (2) production characteristics, including farm size, crop(s) grown, and the cropping practices used; (3) agricultural policies, such as commodity subsidy programs and conservation compliance programs or other government-imposed environmental restrictions; (4) natural resource characteristics, such as soil quality and climate; and finally, (5) area dummies in multi-region models to capture inter-regional differences not accounted for in other variables.

Although the human capital category of variables does not have an analogous counterpart at the aggregate level, the remaining sets often do, and tend to play a large role in diffusion analysis as well as adoption analysis.

Kristina Pounds' thesis "The Diffusion of BT Cotton and Its Impact on the Use of Conventional Pesticides in Cotton Production," 2001, was widely considered for this study[1]. Part of the data used for this study was taken from her thesis. Pounds experiments with a non-linear model for the Bt cotton diffusion and a linear model for the pesticide use. Her findings are that Bt Cotton has unequivocally reduced the use of traditional pesticides. The negative effect of Bt cotton adoption on traditional insecticide use was large and statistically significant.

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[1] Kristina Shori Pounds is a M.S.graduate from the Agricultural and Resource Economics Department at the University of Arizona.

CHAPTER II: A THRESHOLD MODEL OF SEED VARIETY CHOICE AND PESTICIDE USE

The model presented here of seed variety choice and pesticide use, is an extension of Carlson and Wetzstein's (CW) pest control threshold model. Before discussing the CW model, it is first appropriate to define what threshold models are and what are they used for.Saphores says that economic thresholds (ET) and economic injury (EI) are still "the back bone of progressive concepts in … insect pest management" (Poston, Pedigo, and Welch).

Stern et al. gave the most widely accepted definition of economic threshold: it is the "density at which control measures should be initiated to prevent an increasing pest population from reaching the economic injury level (EIL)." Saphores adds, "the ET is thus an operating rule immediately tied to the EIL, which is the lowest pest density that will cause economic damage, where the later is the amount of injury that justifies the cost of artificial control measures."

How could we quantify the amount of injury that triggers some pest control action? Headley formalized Hillebrandt's marginal analysis of pest control, but he redefined the economic threshold, says Saphores as "the level to which a pest should be reduced in order for the marginal revenue from the application of a pesticide to just equal its marginal cost. Hall and Norgaard expanded Headley's model and focused on the optimal timing of a pesticide application."

In the CW model, a producer makes two types of choices. The first one addresses whether insecticides are applied or not to control a target pest. The second addresses the optimal pesticide application rate. In the model presented in this chapter, the producer also chooses which type of seed to plant, conventional cotton seed or Bt variety seed. Bt cotton is itself a pest-control technology, so it can substitute for conventional insecticide applications.

A producer has a choice between four seed choice-pesticide use regimes:

1) plant conventional cotton and do not spray for target pest, 2) plant conventional cotton and spray for target pest, 3) plant Bt cotton and do not spray for target pest and 4) plant Bt cotton and spray for target pest.

2.1 Pest control with conventional cotton

Farm per-acre profits for conventional cotton π_c are

$$\pi_c = py_c - rz_c - F \tag{1}$$

where p is the price of cotton, y_c is conventional cotton yield, r is pesticide application cost, z_c is pesticide applications per acre, and F represents other per acre costs of production. This may include per acre scouting costs to determine levels of pest infestation. Crop yields y_c are

(2) $$y_c = A - an$$

where A is potential yield with no pest damage, n is pest density after pesticide treatments, and a is damage per pest. Post-treatment pest density, n, is

(3) $$n = N e^{-bz_c}$$

where N is pre-treatment pest density and b is a parameter measuring the effectiveness of pesticide applications at reducing pest population. The yield damage, D_c, from a pest infestation is:

(4) $$D_c = aNe^{-bz_c}$$

Additive pest damage functions have been widely used in pest economics to derive optimal thresholds, pesticide doses or both (Headley; Hall and Norgaard; Talpaz and Borosh; Regev, Gutierrez and Feder; Feder and Regev; Regev, Shalit and Gutierrez; Feder; Moffit, Hall, and Osteen; Marra and Carlson; Saphores). One can represent pest damage abatement as a negative exponential function, also commonly used. With a negative exponential damage abatement function, pest numbers decline with pesticide applications, but population declines at a decreasing rate.

(5) $$dn / dz_c = -bNe^{-bz_c} < 0$$

(6) $$d^2n / dz_c^2 = b^2Ne^{-bz_c} > 0$$

The farm profit-maximization problem is:

$$\text{Max } \pi_c = p(A - aNe^{-bz_c}) - rz_c - F \text{ w.r.t. } z_c \tag{7}$$

The first order condition for an interior maximum is:

$$d\pi_c / dz_c = pabNe^{-bz_c} - r = 0 \tag{8}$$

The term $pabNe^{-bz_c}$ is the marginal value product (MVP) and r is the marginal cost (MC) of insecticide applications. Under an interior solution, the optimal rate of pesticide application z^*_c is:

$$z^*_c = (1/b) \ln (pabN/\mathrm{r}) \tag{9}$$

Demand for insecticides decreases with its own price and increases with cotton price, damage per pest, and pre-treatment pest levels.

If pre-treatment pest levels, N, are low enough it may not be profitable to make insecticide applications at all. In this case there would be a corner solution where $z^*_c = 0$.

Let $\underline{z}_c$ represent the minimum practical dosage per acre that a grower can apply. Consider a grower choosing between not spraying for a pest, $z = 0$ and applying one minimum application, $z = \underline{z}_c$. The grower will only apply pesticides if profits are higher than not applying them:

$$p(A - a\, N\, e^{-b\underline{z}_c}) - r\, \underline{z}_c \quad > \quad p(A - aN) \tag{10}$$

The term on the left is profit $\pi(z)$ when $z > 0$ is applied and the term on the right is profits with no pesticide applications $\pi(0)$. Under the interior solution, profits are decreasing in N, but at a decreasing rate:

$$(11) \qquad \partial\pi / \partial N = -r / bN < 0; \qquad \partial^2\pi / \partial N^2 = r / bN^2 > 0.$$

Under the no-application corner solution, profits decline linearly in N. Figure 1 shows $\pi(z)$ and $\pi(0)$ as functions of the pre-treatment pest density, N. The intercept for $\pi(0)$ is greater than the intercept for $\pi(z)$, but so is its slope. The pest density N^a represents the action threshold. Given relative prices, and the pest damage and pesticide effectiveness parameters, it is profitable to apply pesticides only if $N > N^a$. Rearranging equation (10), N^a is:

$$(12) \qquad N^a_c = r\underline{z} / [\, pa(1 - e^{-b\underline{z}}) \,]$$

In Figure 1, N^a is the x-coordinate of the point where the two profit curves $\pi(\underline{z})$ and $\pi(0)$ cross. The action threshold increases as pesticide costs increase, but decrease as cotton price increases and as damage per pest increases.

The curve $\Pi(z = \underline{z})$ represents the level of profits applying a fixed dosage of pesticide for various pest population levels when $N > N^a$. $\Pi(z = z^* > \underline{z})$ represent the profits pesticide dosages are allowed to increase above the minimum level $\underline{z}_c$. This $\underline{z}_c$ corresponds to the z^*_c in equation (9). Although costs are higher, so is the damage reduction with new pesticide application dosage. Hence profits are higher at $\Pi(z = z^* > \underline{z})$ relative to $\Pi(z = \underline{z})$ as N increases.

Even though growers do make discrete pesticide applications, applications vary with respect to compounds and dosage. So for any pest population $N > N^a$ it is reasonable to treat pesticide demand as in equation (9).

2.2 Pest control with Bt cotton

The post treatment pest density for Bt cotton (n_b) as compared to conventional cotton (n_c) is :

$$(13) \qquad n_b = (1 - k)Ne^{-\beta z_b} ; \qquad n_c = Ne^{-bz_c}$$

where k represents the "kill rate" – the percent of the pest population controlled by Bt cotton. Given an initial pest population, Bt seed kills a certain percent of that population even without pesticide applications. It is assumed that $\beta > b$. This implies that the slope of the profit function with respect to N is flatter under Bt cotton.

$$(14) \qquad \partial\pi_c / \partial N = -r / bN < 0; \qquad \partial\pi_b / \partial N = -r / \beta N < 0$$

In other words, greater pest populations reduce profits more under conventional than Bt cotton. The pest damage functions for Bt cotton D_b and conventional cotton D_c are:

$$(15) \qquad D_b = \alpha Ne^{-\beta z_b} ; \qquad D_c = aNe^{-bz_c}$$

where $\alpha = a(1 - k)$ and a once again is the average rate of damage per (surviving) pest, so that $\alpha < a$. Bt cotton offers superior pest control, but growers must pay a higher price for seed in the form of a per acre technology fee, *T*. A grower who purchases and plants Bt cotton faces the following optimization problem with respect to pest control:

(16) $$\text{Max } \pi_b = p(A - \alpha N e^{-\beta z_b}) - r z_b - F - T \quad \text{w.r.t. } z_b \quad \text{s.t. } z_b > \underline{z}$$

where $\underline{z}$ is the minimum practical pest treatment. The first order condition for an interior maximum is:

(17) $$d\pi_b / dz_b = p\alpha\beta N e^{-\beta z_b} - r = 0$$

The demand for pesticides and threshold pest population are:

(18) $$z^*_b = (1/\beta)\ln(p\alpha\beta N / r)$$

(19) $$N^a{}_b = [\, r\,\underline{z} + T\,] \,/\, [\, p\alpha(1 - e^{-\beta\underline{z}})\,]$$

Bt cotton damage abatement suggests that the marginal productivity of pesticide applications is lower for Bt cotton than for conventional cotton. From equation (8) and (17) this implies:

(20) $$pabN\, e^{-bz} > p\alpha\beta N\, e^{-\beta z}$$

A sufficient condition for this inequality to hold is $\alpha\beta < ab$. If this condition holds, then demand for pesticides will be lower with Bt cotton than for conventional cotton

(21) $$z^*_b = (1/\beta)\ln(p\alpha\beta N / r) < z^*_c = (1/b)\ln(pabN / r).$$

2.3 Choice of seed variety and pest control regime

A producer has a choice between four seed choice-pesticide use regimes:

(1) Plant conventional cotton; don't spray for target pest ($z = 0$)

(2) Plant conventional cotton: spray for target pest ($z > 0$)

(3) Plant Bt cotton; don't spray for target pest ($z = 0$)

(4) Plant Bt cotton: spray for target pest ($z > 0$)

A producer will choose the regime that yields that highest per acre profits. Figure 2 shows each regime as a function of pre-treatment pest density, *N*. Beginning with $N = 0$, it is optimal to switch from regime (1) to (2) to (3) to (4) as *N* increases. In areas of very low pest density, one would expect neither sprays for Bt's target pests, nor Bt adoption. Table 1 shows how this area corresponds to the San Joaquin Valley of California or the Texas High Plains where the percentage of infested acres is 2.94% and 48% and adoption of 1% and 13% respectively. The area with Bt adoption and no sprays corresponds closely to Arizona. In other areas, such as the Delta or Southeast, one observes both Bt cotton adoption and oversprays of conventional insecticides. This is the case for Bt cotton acreage in LA and NC where pesticides application are 2.0 and 1.1 per treated acre, respectively.

Table 1. Percentages of Acres Infested, Treated and Adopted in CA, Texas High Plains - TX HP, AZ, LA and NC for the year 2003.

Region	% acres infested (bollworm, budworm, or PBW)*	% acres treated	# of applications per treated acre	% bt cotton adoption
CA	2.94%	0.15%	1.0	1%
TX HP	48.00%	6.67%	1.0	13%
AZ all	89.85%	17.51%	2.4	74%
AZ Bt	89.79%	0.00%	0.0	100%
AZ conv	90.00%	67.19%	2.4	0%
LA all	86.60%	75.00%	2.10	84%
LA Bt	85.00%	75.00%	2.0	100%
LA conv	95.00%	75.00%	2.5	0%
NC all	100.00%	87.22%	1.70	73%
NC Bt	100.00%	82.61%	1.1	100%
NC conv	100.00%	99.53%	3.0	0%

* PBW = Pink bollworm for CA and AZ

Source: Mississippi State University Cotton and Insect Loss Database.
http://www.msstate.edu/Entomology/Cotton.html Accessed 04/2004

2.4 Effect of Bt cotton adoption on optimal pest damage

Optimal pest damage under conventional cotton is

$$(22) \qquad D_c = aN \text{ for } N < N^a{}_c$$

$$D_c = aNe^{-bz_c} \text{ for } N \geq N^a{}_c$$

Substituting the optimal z^*_c into (22) gives:

$$(23) \qquad D_c = aN \text{ for } N < N^a{}_c$$

$$D_c = r/pb \text{ for } N \geq N^a{}_c$$

Optimal pest damage under Bt cotton is

$$(24) \qquad D_b = a(1-k)N \text{ for } N < N^a{}_b$$

$$D_b = r/p\beta \quad \text{for } N \geq N^a{}_b$$

Figure 3, shows optimal pest damage as a function of pre-treatment pest density for Bt and conventional cotton. The damage function has a linear-plateau shape. For Bt cotton, the slope of the damage curve is flatter and the damage plateau is lower than for conventional cotton. In figure 3, the action threshold is greater for Bt cotton $N^a{}_b > N^a{}_c$.

For this to hold the following condition must also hold:

$$(25) \quad N^a{}_b = [\, r\underline{z} + T\,] \,/\, [\, pa(1-k)\,(1 - e^{-\beta \underline{z}})\,] \;>\; N^a{}_c = r\underline{z} \,/\, [\, pa(1 - e^{-b\underline{z}})\,].$$

The technology fee makes the numerator larger for $N^{a}{}_{b}$. The positive kill rate k makes the denominator smaller. As long as these two effects outweigh the effect of $\beta > b$, then the action threshold will be larger under Bt cotton.

The results from equation (23) and (24) suggest that for a given level of prices and pest population, target pest damage will be lower under Bt cotton. The results also suggest that over a range of pest populations, pest damage will vary less under Bt cotton. Under Bt cotton, pest damage ranges from 0 to $r / p\beta$, while under conventional cotton it ranges from 0 to r / pb, being $\beta > b$.

2.5 Effect of Bt cotton adoption on optimal pesticide use

If $\alpha\beta < ab$ and $\beta > b$ hold, then for a given cotton price, pesticide price and pre-treatment pest density the optimal pesticide demand will be lower under Bt cotton than conventional cotton.

The demand for insecticide use is reduced under the Bt cotton regime since Bt acts as a pesticide. Equation (21) shows how the pesticide quantity used is less under the adopters of Bt seed technology than under the conventional regime and profits are maximized after the threshold pest density level N^{s} (switching technology point) is reached as shown in Figure 3. At pest population level, N^{s}, profits for both regimes are the same, but the cost under the Bt regime is higher than the cost under the conventional regime due to the technology fee. (see Figure 5). Hence, the total revenue for Bt is greater than for conventional cotton and if the output price and acreage are the same for both then the only way for revenue under Bt to be greater than the conventional is if yield is greater. We must therefore say that Bt adoption does increase the yield.

(21) $$z^*_b = (1/\beta)\ln(p\alpha\beta N / r) < z^*_c = (1/b)\ln(pabN / r)$$

2.6 Variables affecting the relative profitability of Bt cotton

Figure 2 illustrates graphically how the profitability of Bt cotton relative to conventional cotton increases with pre-treatment pest density, N. This section shows this mathematically. It also shows how changes in other exogenous variables change the relative profitability of Bt cotton. Let π(net) be per acre profits under Bt cotton minus per acre profits under conventional cotton:

(26) $$\pi(\text{net}) = [\ p(A - \alpha N e^{-\beta z^*_b}) - rz^*_b - F - T\ ] - [\ p(A - aNe^{-bz^*_c}) - rz^*_c - F\ ]$$

We consider the case where an interior solution holds because this is representative of much of the Cotton Belt. In figure 2, this is a comparison of π_b and π_c . Substituting in the optimal values of z^*_b and z^*_c from (21) this becomes

(27) $$\pi(\text{net}) = r\,(1/b - 1/\beta) + r\,(z^*_c - z^*_b) - T$$

The first term measures the economic value of reduced pest damage from Bt cotton, the second term is the reduction in insecticide costs from adopting Bt cotton and T is the additional cost of the Bt technology fee. Table 2 summarizes and interprets comparative static results.

Table 2. Variables affecting relative profitability of Bt cotton vs. conventional cotton: results and economic interpretation.

Result	**Economic Interpretation** **Relative profitability of Bt cotton:**
$d\pi(\text{net}) / dN = (r/N)\,(1/b - 1/\beta) > 0$	Increases as pre-treatment pest population increases
$d\pi(\text{net}) / dp = (r/p)\,(1/b - 1/\beta) > 0$	Increases as cotton (output) price increases
$d\pi(\text{net}) / dr = z^*_c - z^*_b > 0$	Increases as the cost of insecticide applications increases
$d\pi(\text{net}) / d\beta = (r/\beta)\, z^*_b > 0$	Increases with greater effectiveness of insecticide sprays on Bt cotton. For a larger *β* per acre profits fall for Bt cotton less rapidly with a greater pest population.
$d\pi(\text{net}) / da = r/(ab) > 0$	Increases as the damage per pest under conventional cotton increases
$d\pi(\text{net}) / d\alpha = -r/(\alpha\beta) < 0$	Decreases as the damage per pest under Bt cotton increases. Alternatively, the profitability of Bt declines as the pre-treatment kill rate from Bt cotton, *k*, declines.
$d\pi(\text{net}) / db = -(r/b)\, z^*_c < 0$	Decreases with greater effectiveness of insecticide sprays on conventional cotton. For a larger *b*, per acre profits for conventional cotton fall less rapidly with a greater pest population. Increased pest resistance to conventional insecticides might be reflected in a decline in *b*.
$d\pi(\text{net}) / dT = -1 < 0$	Decreases as the Bt technology fee (cost of adoption) increases

2.7 Observed differences in insecticide use with endogenous seed choice.

Figure 4 shows how insecticide application rates change as pre-treatment pest density N increases, accounting for the fact that Bt cotton adoption is a choice variable. The upper panel shows the relatively profitability of the four seed choice – pesticide application regimes. The bottom panel shows changes in observed insecticide use as N increases, holding other factors (such as prices) fixed. From equation (21) insecticide use increases at a decreasing rate in N.

$$\begin{aligned} &\partial z^*_b / \partial N = (1/(\beta N) > 0; \quad \partial^2 z^*_b / \partial N^2 = -(1/(\beta N) < 0; \\ &\partial z^*_c / \partial N = (1/(bN) > 0; \quad \partial^2 z^*_c / \partial N^2 = -(1/(\mathrm{b}N) < 0. \end{aligned} \tag{28}$$

Figure 4 shows that for low pest densities, growers plant conventional cotton and apply no insecticides. Once the pest density reaches the action threshold for conventional cotton, insecticide use rises at a decreasing rate. As N increases further, growers shift to Bt cotton without insecticide applications. For the highest levels of N, growers begin to overspray Bt cotton with insecticides.

Several groups have attempted to assess the impact of Bt cotton adoption on insecticide use by comparing mean insecticide application rates for adopters and non-adopters from aggregate data. For example, Rissler published one such report for the Union of Concerned Scientists in June 1999, titled *Review of ERS Report.* Rissler stated, “But in the majority of crops and regions surveyed, there are no statistically significant differences in pesticide use or yield between engineered and non-engineered varieties. In one case, pesticide use increased on the engineered crop and in another case, yield declined in the engineered varieties." Rissler compares means of yield and insecticide use of biotechnology adopters and non-adopters, but does not control for differences in pest pressure.

Another example making the same incorrect comparison of means of insecticide applications is done by Charles Benbrook. Benbrook states, ". . . in Alabama, another high *Bt*-cotton adoption state (62% acres planted), BBW insecticide applications almost doubled from 1997 to 2000," and also, "Some low-adoption *Bt*-cotton states have also markedly reduced BBW acre-treatments. Texas cotton (7% *Bt*-cotton), for example, was treated an average 1.3 times with BBW insecticides in 1995 and 0.65 times in 2000 - about a 50% drop." (Here, BBW stands for budworm/bollworm). Benbrook also makes an incorrect comparison. Alabama is a state with very high pest pressure; this is why the adoption rate is high too. Following the same intuitive sequence of thinking, a state that has low pest pressure, such as Texas, will not adopt Bt cotton and spray a small percentage of their acreage. Why? The answer is simple. Their pest pressure is low and there is no need for pesticide applications or Bt adoption. Why should a grower spray more pesticides on their crop or adopt Bt cotton if he is not expecting to have high pest pressure?

Figure 4 illustrates why comparing means in an uncontrolled setting is not the appropriate way to address this issue. In Figure 4, growers with pest pressure $N < N^s$ will plant conventional cotton, while growers with pest pressure $N > N^s$ will switch to Bt cotton. For non-adopters insecticide applications range between 0 and z_c^+, while for Bt adopters, applications range from 0 and z_b^+. A comparison of means does not account for the fact that adopters are likely to face greater pest pressure! Those comparing means are asking the wrong question. Consider two groups of growers, one group faces pest pressure N^{low} and the other faces pest pressure N^{high} . The growers facing low pressure, plant conventional cotton and apply $z^L{}_c$ insecticides per acre. The growers facing higher pest pressure plant Bt cotton and apply $z^H{}_b$ insecticides per acre. As illustrated, the two groups have identical application rates ($z^L{}_c = z^H{}_b$), By comparing these values directly, one would incorrectly infer that Bt cotton has not reduced insecticide use, because this comparison does not control for pest pressure.

The appropriate question however is this. How many pesticide applications would Bt cotton adopters make if they did not adopt Bt cotton, controlling for pest pressure and other confounding factors? Consider again growers facing pest pressure N^{high} . The theoretical model suggests that this group would apply $z^H{}_c$ if they had not adopted Bt cotton. The reduction in insecticide use from Bt adoption is $z^H{}_c - z^H{}_b$ shown as a vertical line segment in Figure 4.

2.8 Observed differences in pest control costs with endogenous seed choice.

Figure 5 repeats same type of comparison from Figure 4, but this time illustrates shows how pest control costs, including Bt technology fees, change as pre-treatment pest density N increases. Again it accounts for the fact that Bt cotton adoption is a choice variable that depends on N.

Pest control costs, C, are as follows:

Regime (1): conventional cotton; don't spray: $C = 0$

Regime (2): conventional cotton; spray: $C = r\, z^*_c$

Regime (3): Bt cotton; don't spray: $C = T$

Regime (4): Bt cotton; spray: $C = T + r\, z^*_b$

Comparing mean pest control costs between adopters and non-adopters in an uncontrolled setting is also a biased comparison that will understate the cost saving of Bt cotton adoption. With this comparison, total pest control costs of Bt cotton adopters may be higher than costs for non-adopters. Figure 5 shows costs for low pressure and high pest pressure groups. Again, the appropriate counterfactual is pest control costs if adopters did not adopt. This is given by the vertical distance s^* in Figure 5.

2.9 Summary

The model developed in this chapter shows how Bt cotton adoption alters the more traditional threshold approach to controlling pests. The model suggests that Bt cotton adoption is more likely when:

1. Cotton prices are higher

2. Conventional insecticide prices are higher
3. Pre-treatment pest density is higher
4. Bt technology fees are lower
5. Conventional insecticides become less effective at controlling target pests, possibly because of resistance.

This last result may arise if target pests develop resistance to conventional insecticides.

The model can explain why different regions of the Cotton Belt follow different pest control regimes for bollworm, budworm, and pink bollworm. It also suggests a testable hypothesis that both the level and the variance of target pest damage may be lower for Bt cotton.

Finally, the model illustrates why comparison of means from aggregate data often show no reduction in insecticide use or pest control cost savings from Bt cotton adoption, even though pair-wise comparisons in small-plot experiments consistently do find differences. The model illustrates that both Bt cotton adoption and insecticide use depend on pre-treatment pest density, which is often an unobserved variable. Comparing sample means alone can yield biased estimates that understate the impact of Bt cotton adoption.

FIGURES

Figure 1. Profit (*Π)* as a function of pest density *(N)* and the pesticide application threshold (N^a).

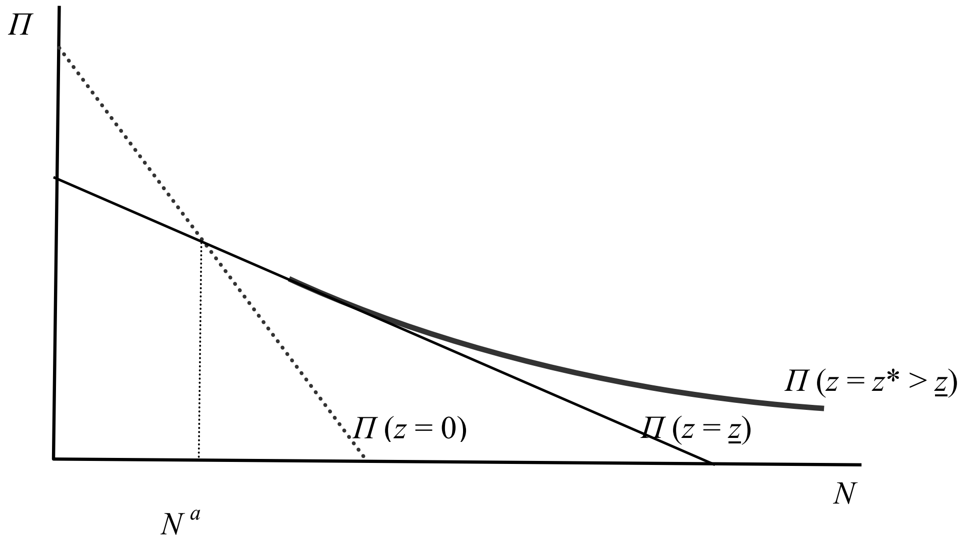


Figure 2. Threshold models

Variable Definitions	
Π^0_c	Per acre profits, conventional cotton, no spray
Π_c	Per acre profits, conventional cotton, spray
Π^0_b	Per acre profits, Bt cotton, no spray
Π_b	Per acre profits, Bt cotton, spray
N	Pest density

Per acre profits (Π) as a function of pest density (N) under different seed and spray regimes

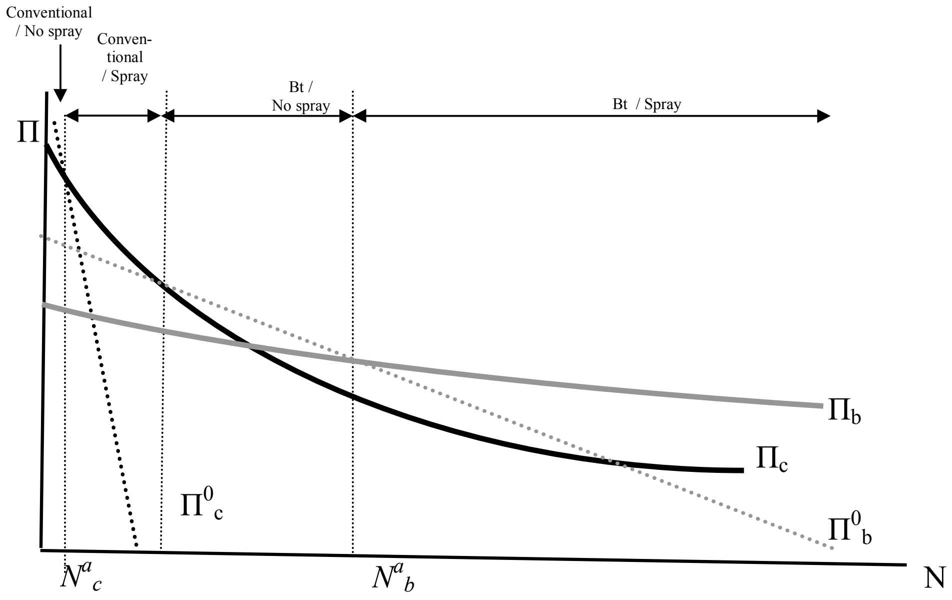


Figure 3. Pest damage functions for Bt (D_b) and conventional cotton (D_c) as a function of pest density

Variable Definitions	
Π^0_c	Per acre profits, conventional cotton, no spray
Π_c	Per acre profits, conventional cotton, spray
Π^0_b	Per acre profits, Bt cotton, no spray
Π_b	Per acre profits, Bt cotton, spray
N	Pest density

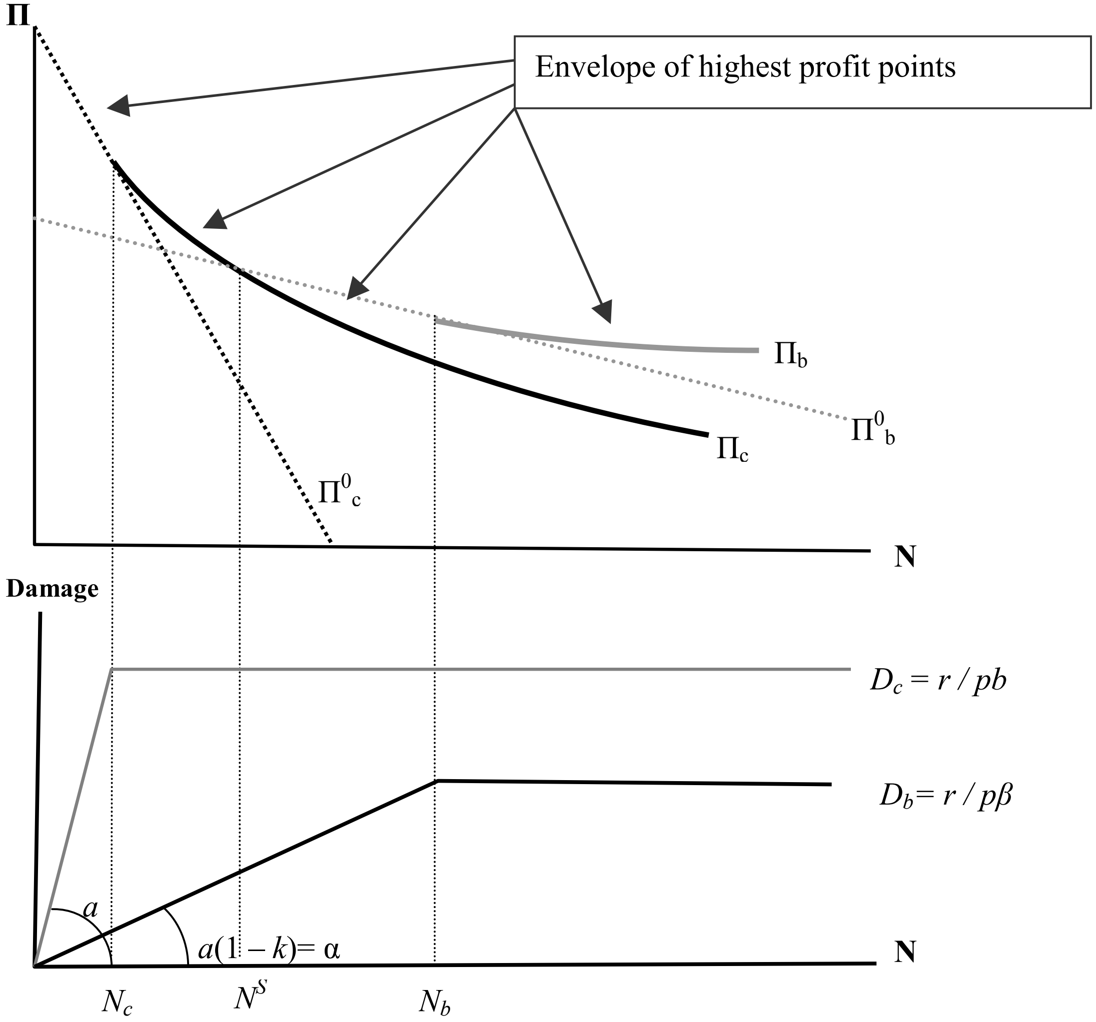


Figure 4. Insecticide applications (*z)* and profits (*Π)* vs. pest population *(N)*.

Variable Definitions	
Π^0_c	Per acre profits, conventional cotton, no spray
Π_c	Per acre profits, conventional cotton, spray
Π^0_b	Per acre profits, Bt cotton, no spray
Π_b	Per acre profits, Bt cotton, spray
N	Pest density
z_c	Insecticide use, conventional cotton
z_b	Insecticide use, Bt cotton

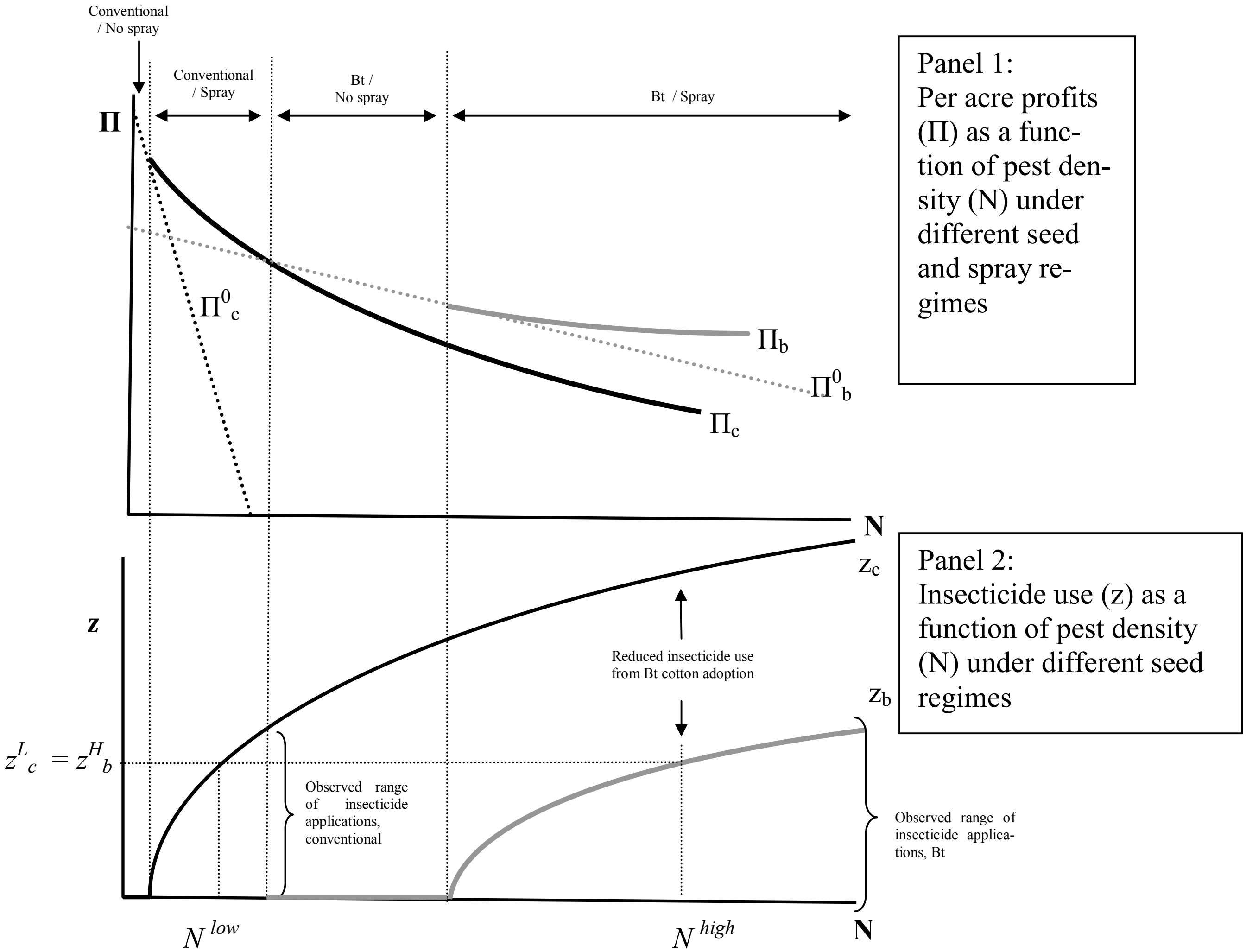
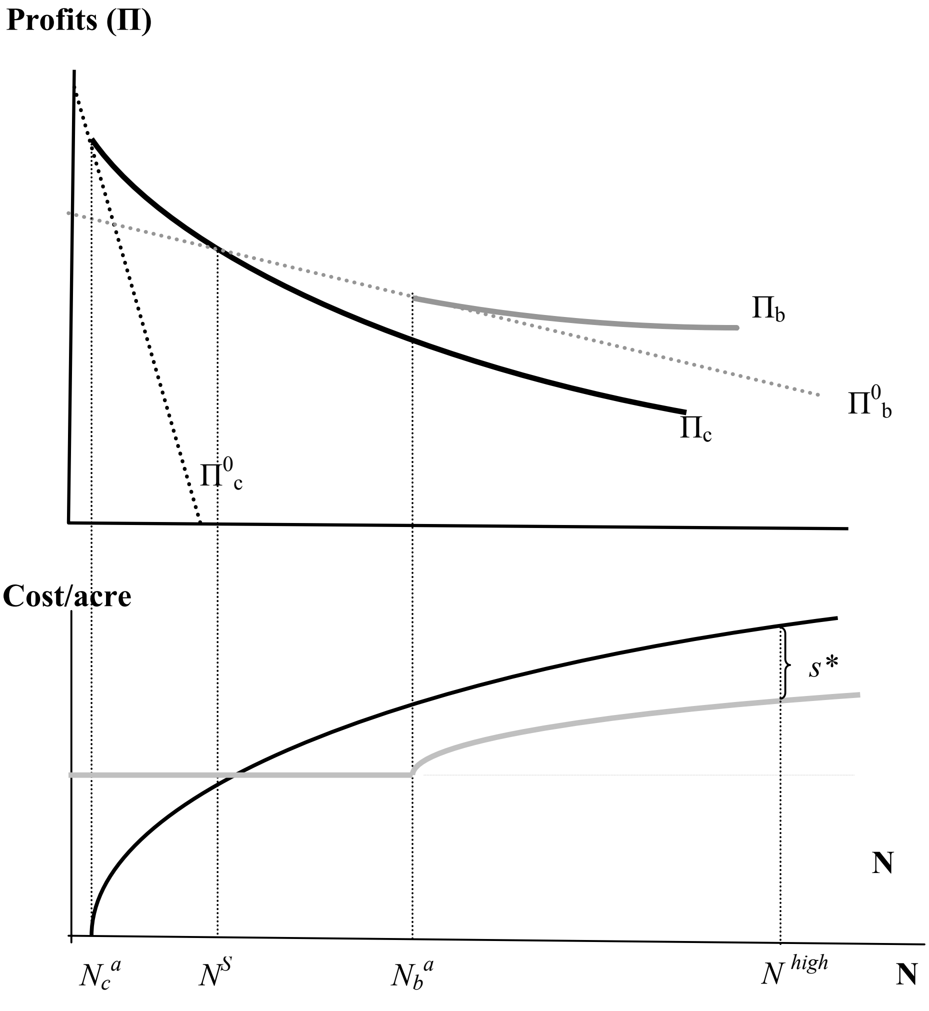


Figure 5. Costs of adopters and non-adopters facing low and high pest pressures (N^{high})

Variable Definitions	
Π^0_c	Per acre profits, conventional cotton, no spray
Π_c	Per acre profits, conventional cotton, spray
Π^0_b	Per acre profits, Bt cotton, no spray
Π_b	Per acre profits, Bt cotton, spray
N	Pest density
N_c^a	Threshold pest density level for conventional cotton
N^S	Switching technology pest density level
N_b^a	Threshold pest density level for Bt cotton



CHAPTER III:

DIFFERENCES IN PEST DAMAGE AND CONTROL COSTS BETWEEN BT AND CONVENTIONAL COTTON:

SIMPLE HYPOTHESIS TESTS USING STATE-LEVEL DATA

3.1 Introduction

Most of the empirical findings regarding the performance of Bt cotton are based on small-scale, experimental or plot–level farm studies (Gianessi et al. 2002, NCFAP). Performance measures include yield, boll damage from target pests, insecticide applications, and pest control costs. Means of these variables are compared between Bt and non-Bt plots. An advantage of this design is that they control for differences other than seed variety choice. When comparing means from plots with the same soil type, weather, insect pressure, or grower attributes, the use of Bt seed is a treatment and its impact can be isolated. A limitation of this approach is that for policy purposes, decision-makers often want measures of more aggregate impacts of Bt cotton adoption. The NCFAP study derives national impacts by extrapolating results from small, plot-level studies to entire states or groups of states (Gianessi et al. 2002, NCFAP). This type of extrapolation could give biased results if plot-level results are not representative of larger areas.

Representative farm surveys and state-level statistics, can address this one source of bias. They also reflect responses to real agronomic and economic conditions, rather than experimental ones. Means from farm surveys, state, or regional statistics, however, are the result of uncontrolled experiments. Many things, besides Bt cotton adoption can account for differences in means of yield or insecticide use. Some examples are differences in pest pressure, weather, irrigation, grower attributes, or participation in a boll weevil eradication program.

By failing to account for these other factors, comparison of means can give biased and misleading results (Fernandez-Cornejo and McBride, Heimlich, et al.). Growers are not assigned randomly to treatment (Bt cotton adopter) and control (non-adopter) groups. Rather they choose whether or not to adopt Bt cotton based on factors that also influence yield and insecticide use. Failure to account for this can lead to sample selection bias. For example, as the last chapter showed, growers who expect to face higher pre-treatment densities of target pests are more likely to adopt Bt cotton, while those in areas with low pest pressure will not adopt. Simply comparing means between the two groups does not account for the fact that non-adopters (on average) face less target pest pressure. This will bias tests toward failing to reject a null hypothesis that Bt cotton has no impact on insecticide use.

Results from Carlson, Marra and Hubbell are consistent with this effect. Their study compared insecticide applications of Bt adopters on their Bt plots, Bt adopters on their non-Bt plots, and non-adopters. They found that, on their Bt plots, Bt adopters applied fewer insecticides than non-adopters. Growers in North Carolina and South Carolina (the Upper South) made 0.9 applications per total acre on their Bt acres versus 3.3

applications on their non-Bt acres. For Alabama and Georgia (the Lower South) growers made 0.7 applications per total acre on their Bt acres vs. 2.6 applications on their non-Bt acres . They also found adopters applied more insecticides on their non-Bt plots than did non-adopters. For example, in the Upper South Bt adopters sprayed 3.3 applications per total acre in their non-Bt acres vs 2.9 applications per total acre for the non-Bt cotton adopters. For the Lower South, Bt adopters made 2.6 applications for non-Bt acres versus 1.8 applications by non-adopters. These results suggest that adopters of Bt cotton faced greater underlying pest pressure.

Table 3. Impacts of Bt Cotton Adoption on Insecticide Applications: Southeast U.S. 1996-7

REGION	Bt Cotton Adopters		**Bt Cotton Non-Adopters**
	Bt Acres	Non-Bt Acres	
	Applications/ Acre	Applications/ Acre	Applications/Acre
Upper South (NC, SC)	0.9	3.3	2.9
Lower South (AL, GA)	0.7	2.6	1.8

Source: Carlson, Marra and Hubbell

3.2 Methods

Keeping in mind the potential for bias, some simple hypothesis tests of differences in means and variances of pest damage, insecticide use, and pest control costs between the

Bt and non-Bt acreage were conducted using state-level data. Separate effects were considered for target pests and for all pests. The three main target lepidopteran pests that Bt cotton is meant to control are cotton bollworm (*Helicoverpa zea*), tobacco budworm (*Heliothis virescens*), and pink bollworm (*Pectinophora gossypiella*). There is some evidence that reduced sprays for target pests may increase populations of secondary pests, which require other sprays (Gianessi et al. 2002, NCFAP). Simple one-tailed t-tests were used to test differences in means. For example, the null hypothesis that insecticide applications were equal for Bt and non-Bt acreage was tested against the alternative that applications were lower on Bt acreage.

3.3 Data

The Beltwide Cotton Insect Losses Survey has been supported by the National Cotton Council since 1979. The data provided is reported by state, selected sub-state regions, and year since 1979. This data includes: bales lost per pest, acres infested per pest, acres treated per pest, number of insecticide applications per pest, total acres planted, acres planted to Bt cotton (since 1996), cost of one application, applications costs per total acres harvested and percent yield reduction based on bales lost per pest, total bales lost and average percent loss. This data has multiple uses. It is used to track pest density changes, new pest developments and pest eradication. The Boll Weevil Eradication programs are very important to follow, because they also kill predators of pink bollworms, cotton bollworms and tobacco budworms, allowing the cotton to be more vulnerable to these pests. Therefore it is important to track these eradication programs and their impact on Bt cotton adoption. The availability of all information is useful in the development for new policy controls. These data are useful to bankers, marketing interests, insurers, regulators and researchers, by being able to estimate with independent data, pesticide use and insect-related losses. State-level data is available from the internet at no cost from The Cotton Crop Loss (CCL) database which is maintained by The Mississippi State University.

Since 1999, some state coordinators have begun reporting data separately for acres planted to Bt and non-Bt varieties. These include Arizona (1999-2002), Louisiana (1999-2002), Tennessee (1999, 2002), North Carolina (2000-2002), Georgia (2002), and South Carolina (2002). Pooled together, there are 30 observations, 15 Bt observations and 15 non-Bt observations. These 30 observations are the data used in this chapter.

3.4 Results

Bt acreage suffered less damage from bollworm, budworm and pink bollworm than non-Bt acreage. Non-Bt cotton averaged yield losses of 4.1 percent or 0.09 bales (43.1 pounds) per acre, while Bt cotton averaged yield losses of 0.91 percent or 0.02 bales (9.6 pounds) per acre. (Table 4). One cotton bale is 480 pounds. Growers treated Bt acreage less extensively and less often for bollworm, budworm and pink bollworm. While 75.6 percent of non-Bt acres infested with these pests were treated, less than 53 percent of infested Bt acres were treated. Applications per total cotton acres were 2.31 for non-Bt cotton and 0.73 for Bt cotton. Non-Bt cotton received 3.28 applications per treated acre compared to 1.09 applications for Bt cotton. The statistical significance of all these differences was high using a one-tailed t-test assuming unequal variances. The difference in acres treated as a percent of acres infested was significant at the 2 per cent level, while all the other differences were significant at a less than 0.1 percent level.

Results are similar for differences in damage and applications to control all cotton pests. Yield loss on non-Bt acres averaged 7.43 percent or 0.17 bales (82.8 pounds) per acre, while yield loss on Bt acres averaged 4.75 percent or 0.11 bales (53.3 pounds) per acre. There was less of a difference in mean applications for all pests between Bt and non-Bt cotton. Still, non-Bt acre averaged 5.15 applications per total acres versus 3.77 applications for Bt cotton. Using a one-tailed t-test, either assuming unequal variances or not, the differences were all significant at the 5 percent level.

The variances of damage and insecticide use variables were lower for Bt cotton than non-Bt cotton, with the exception of applications per total cotton acres for all pests (Table 5). Results fail to reject the hypothesis that the variances are equal for variables related to all cotton pests, using an F-test. For variables related to bollworm, budworm and pink bollworm, the hypothesis of equal variances for percent yield loss and bales lost per acre is rejected at a less than 0.1 percent significance level. The hypothesis of equal variances for applications per total acre was rejected at the 5 percent level.

Pest control costs, including Bt technology fees, were slightly higher on Bt acres than non-Bt acres, $86.55 compared to $82.13 (Table 6). The variance of pest control costs was lower for Bt than non-Bt cotton. The hypotheses of equal means or equal variances could not be rejected.

3.5 Discussion

The above results suggest that pest damage and insecticide use are different on Bt and non-Bt acreage. The results do not control for other factors, so the simple tests here cannot say how much of these differences are *because* of Bt cotton. The hypothesis that means and variances of total pest control costs were equal on Bt and non-Bt acreage could not be rejected. Total pest control costs include the higher cost of Bt cotton seed. Again, confounding factors may bias results. Bt cotton adopters are likely to face higher pest pressure than non-adopters.

TABLES

Table 4. Comparison of pest damage and insecticide use, Bt vs. non-Bt cotton, pooled years and states

	Non-Bt	**Bt**	**t value**	**Significance level***
All cotton pests				
Percent yield loss	7.43	4.75	2.87	0.004
Bales lost per acre	0.17	0.11	2.40	0.012
Applications per total cotton acres	5.15	3.77	1.81	0.041
Bollworm, budworm, and pink bollworm				
Percent yield loss	4.10	0.91	5.20	0.000
Bales lost per acre	0.09	0.02	6.49	0.000
Applications per total cotton acres	2.31	0.73	4.60	0.000
Acres treated as % of acres infested	75.60	52.98	2.15	0.021
Applications per treated acre	3.28	1.09	5.20	0.000

* Significance level of one-tailed t-test of difference in means

Table 5. Comparison of variances of pest damage and insecticide use variables, Bt vs. non-Bt cotton, pooled years and states

	Variance Non-Bt	Variance Bt	F statistic	Significance level*
All cotton pests				
Percent yield loss	8.34	4.76	1.75	0.15
Bales lost per acre	0.007	0.003	2.29	0.07
Applications per total cotton acres	4.08	4.69	1.15	0.40
Bollworm, budworm and pink bollworm				
Percent yield loss	5.11	0.54	9.54	0.0001
Bales lost per acre	0.0016	0.0002	8.29	0.0002
Applications per total cotton acres	1.26	0.51	2.48	0.05
Acres treated as % of acres infested	1157.78	508.66	1.69	0.17
Applications per treated acre	1.50	0.69	2.17	0.08

* Significance level of one-tailed F-test of difference in variances

Table 6. Comparison pest control costs, Bt vs. non-Bt cotton, pooled years and states

	Non-Bt	Bt	Significance level
Mean pest control costs per acre	$82.13	$86.55	0.352[a]
Variance of pest control costs per acre	1176.37	829.51	0.261[b]

a. Significance level of t-test of difference in means.
b. Significance level of F-test of difference in variances.

CHAPTER IV:
SUMMARY AND CONCLUSIONS

Aside from localized pair-wise comparisons, as stated in chapter II of this thesis, one could estimate the effects of Bt cotton adoption using multivariate regression analysis. This multivariate analysis would have to control for confounding factors and possible bias from the endogeneity of the Bt cotton adoption decision.

4.1 Limitations of current study

This study does not account for impact that the randomness of a pest population could have on pesticide use or seed choice. The presented model doesn't account for, nor deals with, uncertainty or farmer risk aversion. In real life, farmers make their seed choice before they know what is their actual pest pressure. Farmers make their seed choice based on expected pest pressure and may rely on the previous years' experiences. There have been some attempts to address the problem of uncertainty related to pest control. Feder investigated, qualitatively, the effect on the dosage of a pesticide by a risk averse farmer. He considered uncertainty in the rate of damage per pest, in the size of the pest population, and in the efficacy of the pesticide. Mangel used a continuous-time formulation; he showed how to incorporate pest age structure, the random arrival rate of pests, and the stochastic effect of a pesticide on pest growth rate. However, his stochastic model requires biological information that is often unavailable and its numerical resolution ap pears challenging. Saphores says, “For practical uses, a compromise has to be found between the realism of a model and its usability.” To date, the impact of uncertainty in the evolution of the pest population on decision to use pest control measures does not appear to have been solved satisfactorily.

4.2 Restatement of Main Findings

The study on chapter III reports on differences in means and variances of pest damage, insecticide use, and pest control costs between Bt and non-Bt acreage using state-level data. Some statistically significant differences are as follows. Insecticide applications for both target pests and all pests were lower on Bt acreage. Yield losses from target and all pests were lower on Bt acreage. The variance of yield losses from target pests was lower for Bt cotton. The hypothesis that means or variances of overall pest control costs (which include Bt fees) were equal on Bt and non-Bt acreage could not be rejected.

APENDIX A: DATA USED IN CALCULATIONS

		Bollworm/Budworm/ Pink Yield Percent Lost		**Bollworm/Budworm/ Pink Bales Lost Per Total Acre**		**Bollworm/Budworm/ Pink Applications per Total Acre**	
State	Year	conventional	bt	conventional	bt	conventional	bt
Arizona	1999	2.550	0.179	0.076	0.006	0.900	0.033
Arizona	2000	3.230	0.000	0.112	0.000	1.560	0.000
Arizona	2001	3.851	0.000	0.128	0.000	1.326	0.000
Arizona	2002	2.400	0.000	0.085	0.000	1.680	0.000
Lousiana	1999	1.010	0.640	0.019	0.012	1.804	0.834
Lousiana	2000	2.797	0.623	0.048	0.011	4.538	0.914
Lousiana	2001	2.918	1.168	0.061	0.024	2.292	0.916
Lousiana	2002	3.000	1.920	0.066	0.042	4.230	2.570
Tennessee	1999	3.007	0.805	0.061	0.016	1.242	0.251
Tennessee	2002	9.370	2.070	0.160	0.035	1.320	0.904
NC	2000	5.560	1.260	0.145	0.033	2.742	0.866
NC	2001	8.000	1.580	0.135	0.027	1.850	0.613
NC	2002	3.000	0.600	0.050	0.011	2.336	0.880
GA	2002	4.790	0.750	0.100	0.016	3.425	0.336
SC	2002	6.000	2.000	0.100	0.035	3.333	1.768
Means		**4.099**	**0.906**	**0.090**	**0.018**	**2.305**	**0.726**

Source: Misisippi State University Cotton and Insect Loss Database.

http://www.msstate.edu/Entomology/Cotton.html Accessed 03/2003

t-Test: Two-Sample Assuming Unequal Variances

	conventional	*bt*	*conventional*	*bt*	*conventional*	*bt*
Mean	4.098893	0.9063	0.089731	0.0179	2.305215	0.72566179
Variance	5.112069	0.5356	0.00164	0.0002	1.259349	0.50686713
Observations	15	15	15	15	15	15
Hypothesized Mean Difference	0		0		0	
Df	17		17		24	
t Stat	5.203043		6.493773		4.60318	
P(T<=t) one-tail	3.59E-05		2.75E-06		5.7E-05	
t Critical one-tail	1.739606		1.739606		1.710882	
P(T<=t) two-tail	7.18E-05		5.51E-06		0.000114	
t Critical two-tail	2.109819		2.109819		2.063898	

t-Test: Two-Sample Assuming Equal Variances						
(*)Pink bollworm for AZ only	**Bollworm/Budworm/ Pink Yield Percent Lost**		**Bollworm/Budworm/ Pink Bales Lost Per Total Acre**		**Bollworm/Budworm/ Pink Applications per Total Acre**	
	conventional	*bt*	*conventional*	*bt*	*conventional*	*bt*
Mean	4.098893	0.9063	0.089731	0.0179	2.305215	0.72566179
Variance	5.112069	0.5356	0.00164	0.0002	1.259349	0.50686713
Observations	15	15	15	15	15	15
Pooled Variance	2.823832		0.000919		0.883108	
Hypothesized Mean Difference	0		0		0	
df	28		28		28	
t Stat	5.203043		6.493773		4.60318	
P(T<=t) one-tail	7.96E-06		2.45E-07		4.1E-05	
t Critical one-tail	1.70113		1.70113		1.70113	
P(T<=t) two-tail	1.59E-05		4.9E-07		8.2E-05	
t Critical two-tail	2.048409		2.048409		2.048409	
F-Test Two-Sample for Variances						
	conventional	*bt*	*conventional*	*bt*	*conventional*	*bt*
Mean	4.098893	0.9063	0.089731	0.0179	2.305215	0.72566179
Variance	5.112069	0.5356	0.00164	0.0002	1.259349	0.50686713
Observations	15	15	15	15	15	15
df	14	14	14	14	14	14
F	9.544639		8.288907		2.484574	
P(F<=f) one-tail	7.05E-05		0.000159		0.049938	
F Critical one-tail	2.483723		2.483723		2.483723	

(*)Pink bollworm for AZ only		**All Pests/Yield Percent Lost**		**All Pests/Bales Lost Per Total Acre**		**All Pests / Applications per Total Acre**	
t-Test: Two-Sample Assuming Unequal Variances. Ho: Equal Means for Convententional and Bt							
		conventional	*bt*	*conventional*	*bt*	*conventional*	*bt*
Mean		**7.43**	**4.75**	**0.17**	**0.11**	**5.15**	**3.77**
Variance		8.34	4.76	0.01	0.00	4.08	4.69
Observations		15.00	15.00	15.00	15.00	15.00	15.00
Hypothesized Mean Difference		0.00		0.00		0.00	
df		26.00		24.00		28.00	
t Stat		2.87		2.40		1.81	
P(T<=t) one-tail		0.00		0.01		0.04	
t Critical one-tail		1.71		1.71		1.70	
P(T<=t) two-tail		0.01		0.02		0.08	
t Critical two-tail		2.06		2.06		2.05	
Pairs of Means underlined and bold are significantly different according to t-test (P=0.05)							
t-Test: Two-Sample Assuming Equal Variances. Ho: Equal Means for Convententional and Bt							
		conventional	*bt*	*conventional*	*bt*	*conventional*	*bt*
Mean		**7.43**	**4.75**	**0.17**	**0.11**	**5.15**	**3.77**
Variance		8.34	4.76	0.01	0.00	4.08	4.69
Observations		15.00	15.00	15.00	15.00	15.00	15.00
Pooled Variance		6.55		0.00		4.39	
Hypothesized Mean Difference		0.00		0.00		0.00	
df		28.00		28.00		28.00	
t Stat		2.87		2.40		1.81	
P(T<=t) one-tail		0.00		0.01		0.04	
t Critical one-tail		1.70		1.70		1.70	
P(T<=t) two-tail		0.01		0.02		0.08	
t Critical two-tail		2.05		2.05		2.05	
Pairs of Means underlined and bold are significantly different according to t-test (P=0.05)							

F-Test Two-Sample for Variances. Ho: Equal Variances for Conventional and Bt							
(*)Pink bollworm for AZ only		**All Pests/Yield Percent Lost**		**All Pests/Bales Lost Per Total Acre**		**All Pests / Applications per Total Acre**	
		conventional	*bt*	*conventional*	*bt*	*bt*	*conventional*
Mean		7.43	4.75	0.17	0.11	3.77	5.15
Variance		8.34	4.76	0.01	0.00	4.69	4.08
Observations		15.00	15.00	15.00	15.00	15.00	15.00
df		14.00	14.00	14.00	14.00	14.00	14.00
F		1.75		2.29		1.15	
P(F<=f) one-tail		0.15		0.07		0.40	
F Critical one-tail		2.48		2.48		2.48	
Pairs of Variances underlined and bold are significantly different according to F-Test (P=0.05)							

*Pink bollworm for AZ only		**Bollworm/Budworm/Pink Percent Acres Infested***		**Bollworm/Budworm/Pink Percent Acres Treated/Infested***		**Bollworm/Budworm/Pink Appl per Treated Acre***	
State	Year	conventional	bt	conventional	bt	conventional	bt
Arizona	1999	85.000	85.000	20.001	10.770	5.294	0.360
Arizona	2000	85.000	90.000	41.176	21.726	4.457	0.000
Arizona	2001	99.000	99.000	60.606	0.000	2.210	0.000
Arizona	2002	100.000	95.000	70.000	0.000	2.400	0.000
Lousiana	1999	95.017	90.176	93.115	63.749	2.190	1.451
Lousiana	2000	97.451	88.929	89.548	51.366	5.200	2.000
Lousiana	2001	87.118	88.462	79.724	73.998	3.300	1.400
Lousiana	2002	100.000	96.194	90.000	86.174	4.700	3.100
Tennessee	1999	97.000	97.000	80.000	23.500	1.601	1.101
Tennessee	2002	95.149	90.000	53.377	83.677	2.599	1.200
NC	2000	100.000	100.000	97.922	86.585	2.800	1.000
NC	2001	100.000	100.000	92.515	68.116	2.000	0.900
NC	2002	100.000	100.000	93.443	80.000	2.500	1.100
GA	2002	95.890	74.627	89.286	45.000	4.000	1.001
SC	2002	100.000	100.000	83.333	100.000	4.000	1.768
Means		**95.775**	**92.959**	**75.603**	**52.977**	**3.283**	**1.092**
t-Test: Two-Sample Assuming Unequal Variances							
		conventional	*bt*	*conventional*	*bt*	*conventional*	*bt*
Mean		95.7750539	92.9592053	75.6030342	52.9773294	3.28337334	1.092106053
Variance		30.7101197	51.92027	508.656259	1157.7793	1.50370499	0.694040917
Observations		15	15	15	15	15	15
Hypothesized Mean Difference		0		0		0	
df		26		24		25	
t Stat		1.19973417		2.14661166		5.72469357	
P(T<=t) one-tail		0.12053071		0.02107048		2.8968E-06	
t Critical one-tail		1.70561634		1.71088232		1.70814019	
P(T<=t) two-tail		0.24106141		0.04214095		5.7936E-06	
t Critical two-tail		2.05553079		2.06389814		2.05953711	

t-Test: Two-Sample Assuming Equal Variances

*Pink bollworm for AZ only	**Bollworm/Budworm/Pink Percent Acres Infested***		**Bollworm/Budworm/Pink Percent Acres Treated/Infested***		**Bollworm/Budworm/Pink Appl per Treated Acre***	
	conventional	*bt*	*conventional*	*bt*	*conventional*	*bt*
Mean	95.7750539	92.9592053	75.6030342	52.9773294	3.28337334	1.092106053
Variance	30.7101197	51.92027	508.656259	1157.7793	1.50370499	0.694040917
Observations	15	15	15	15	15	15
Pooled Variance	41.3151949		833.217778		1.09887295	
Hypothesized Mean Difference	0		0		0	
df	28		28		28	
t Stat	1.19973417		2.14661166		5.72469357	
P(T<=t) one-tail	0.1201481		0.02031572		1.9243E-06	
t Critical one-tail	1.70113026		1.70113026		1.70113026	
P(T<=t) two-tail	0.2402962		0.04063144		3.8485E-06	
t Critical two-tail	2.04840944		2.04840944		2.04840944	

F-Test Two-Sample for Variances

	conventional	*bt*	*conventional*	*bt*	*conventional*	*bt*
Mean	95.7750539	92.9592053	75.6030342	52.9773294	3.28337334	1.092106053
Variance	30.7101197	51.92027	508.656259	1157.7793	1.50370499	0.694040917
Observations	15	15	15	15	15	15
Df	14	14	14	14	14	14
F	0.59148613		0.43933784		2.16659415	
P(F<=f) one-tail	0.16861004		0.06793219		0.0801511	
F Critical one-tail	0.40262105		0.40262105		2.48372345	

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