Economics of Bt cotton refuge requirements

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ABSTRACT

To slow development of resistance to Bt cotton, the U.S. Environmental Protection Agency has required the planting of refuges of non-Bt cotton. In the short run, refuges are costly to individual growers who must forego benefits of Bt cotton on part their acreage. In the long run, refuges can increase the profits of growers collectively because they extend the number of years Bt cotton varieties are effective. The net benefits or costs of a refuge can be characterized in terms of two key variables: (a) the number of years it takes resistance to develop without a refuge and (b) the number of additional years of Bt effectiveness a refuge provides. This paper illustrates simple methods to estimate costs and benefits of refuges, given limited economic information and a high degree of scientific uncertainty about the dynamics of resistance, using an example from cotton production in the Southwestern United States. These are intended to be useful to agencies involved with Bt cotton resistance management in developing as well as developed countries.

Introduction

The Bt gene (Bt) is a naturally occurring bacterium found in the soil. It produces crystal like proteins that kill specific groups of insects. These are called Cry-proteins and when the insect eats the Cry proteins, its own digestive system activates the toxic form of the protein. Susceptible insects feed and within a short amount of time, their intestinal walls rupture and the insects die within a short amount of time – usually just a few days.

Bt cotton primarily targets three pests in the USA – tobacco budworm, bollworm, and pink bollworm. These pests cause more damage to cotton than any other insect pest in the U.S. cotton belt. In 1995, the year prior to Bt cotton introduction, tobacco budworms, cotton bollworms, and pink bollworms reduced U.S. cotton yields by over 4% (Williams, 1996) – or by quarter billion dollars worth of cotton. Nationally, cotton growers averaged 2.4 insecticide applications to control bollworms and budworms, with the average ranging from 6.7 in Alabama to virtually none in California (Williams, 1996). Costs averaged nearly $25 per hectare per application.

Previous studies have credited Bt cotton adoption with sizeable gains for U.S. producers. Gianessi and Carpenter (1999) estimate benefits of $92.7 million in 1998, while Carpenter and Gianessi (2001) estimate benefits of $99 million in 1999. Falck-Zepeda, Traxler and Nelson (1999) estimate producer benefits ranging from $80–$141 million. Frisvold and Tronstad (2002) estimated that benefits to Bt cotton adopters grew from $57 million in 1996 to $97 million in 1998. On a per hectare basis, estimates of benefits range from $50 to $125.

The preservation of the Bt technology is important for several reasons. First, bollworms, budworms, and pink bollworms develop resistance to foliar applications of insecticides. Second, the use of insecticides is tied to environmental concerns. One of the things that make Bt different is that in conventional pesticides, the way to control resistance building is to limit their use. In the case of Bt, the only way to limit its use is to restrict acreage. Insecticides used against budworms and bollworms often create other problems such as higher populations of other pests in the environment. Repeated exposure of insect pests to insecticides has the result of resistance by the insect to the insecticide, which reduces its effectiveness, which will increase crop losses, lead to higher insect control costs and lower profits.

When target insects feed on Bt cotton, the most susceptible are killed, while those that survive are resistant. (USDA). Those that are resistant will survive to adulthood and pass on the resistance genes to future generations. With widespread adoption of Bt cotton, resistance can potentially develop in a few short years. One way to slow resistance is for cotton producers to plant a certain percent of non-Bt cotton adjacent to their Bt cotton fields. These non-Bt fields act as a refuge for susceptible pests. These pests survive to breed with resistant pests and slow resistance.

What are the costs and benefits of Bt cotton refuge requirements?

In the short-run, refuges pose a cost to the growers. Cotton growers must give up additional benefits from Bt cotton on their refuge acres. Yields will be lower and costs will be higher on the fields kept as refuges. Planting refuges also reduces sales of Bt cotton by seed suppliers. However, in the long run overall benefits from Bt cotton can be higher with refuges in place. Bt cotton will be effective (and benefit growers) for more years. Refuges also protect against development of resistance to Bt microbial foliar insecticide sprays used by organic producers, conventional producers, and households.

Managing resistance to Bt cotton, involves an intertemporal trade-off. Refuges can benefit growers collectively in the long run, but they are costly to growers individually in the short run. Individual producers have little short term incentive to plant refuges. In the U.S., the Environmental Protection Agency (EPA) (2002) mandates that all growers planting Bt cotton have a refuge in place. Non-compliance can result in a revocation of a producer's license to plant Bt seed in the future.

U.S. refuge requirements

The costs and benefits of refuges will depend on the options available for refuges. In 1996, the first year of Bt cotton, there were refuge requirements that lasted for 5 years, inclusive of 1996 making the initial registration end in 2000. The rules of the refuge were the following two options:

(1) 96:4 unsprayed refuge: In this option, growers could plant 96% of acres with Bt cotton and 4% had to be kept as a refuge. For every 96 acres of cotton planted to Bt, 4 acres had to be kept as a refuge. No sprays for control of budworms or bollworms could be made.

(2) 80:20 sprayed refuge: growers who use this option must keep 20% as a refuge and are allowed to spray insecticides for bollworms and budworms, except foliar Bt. In other words, for every 80 acres of Bt cotton planted, 20 acres must be kept as a refuge.

Neither of the above options had a distance requirement.

In 2000, the initial registration for Bt expired and the Environmental Protection Agency (EPA) granted a one-year extension of the initial rules for refuges. However, there were some slight changes to the in the requirements. The 96:4 option became a 95:5 option. For every 95 acres of cotton planted to Bt, five acres had to be kept as a refuge. But, this option has two different ways in which to administer it. The first is that the 95:5 holds a five percent refuge and the no spray continues. In this option, the refuge may not be treated with any insecticide that is labelled for use on bollworm, budworm or pink bollworm. Also, the unsprayed refuge must average 150 feet wide and be within ½ mile of the Bt field.

The second is that the 5% may be embedded in the field. The main benefit of this option is that when the field associated with Bt is treated with any insecticide, the embedded refuge may be treated with the same insecticide at the same rate within 24 hours. As an example, if the entire field needs to be treated for bollworms, the same insecticide can be used at the same rate on the embedded refuge. The 5% refuge cannot be treated unless the 95 acres are also sprayed. The 5% refuge can either be placed as a block within the field, or for very large fields, placed in several areas in the field. The refuge must be at least 15 feet wide. For areas such as California, Arizona, and New Mexico where pink bollworm is the main pest, cotton producers are allowed to mix rows of non-Bt cotton and Bt cotton seed. One way to do this is to alternate the seed hopper boxes on the planters. These states are the only ones that allow the rows to be interspersed.

The 80:20 option remained the same. For every 80 acres of Bt cotton planted, at least 20 acres must be kept as a refuge. That refuge may be treated with any insecticide, except foliar applications of Bt. The distance requirement for this option is one mile.

A new change to the refuge requirements is the addition of a community refuge plan. This option was added because there are several producers whose field size is such that they cannot have an associated field within half to one mile from their Bt cotton. Therefore, a group of farmers that wanted to go together to form a community to meet the refuge option is now acceptable. In this case, the rules that apply in the other options apply to everyone in the community and the community is treated as a single producer. All the growers in the community must sign the technology agreement along with field maps that indicate the impossibility of the grower making the requirements on his own. The community appoints a leader and that leader is responsible for making sure that all participating comply with the rules. Those that don't comply will cause everyone participating in the community to fail.

For those producers that raise corn, an 80:20 option is in place. This means that for every 80 acres of Bt corn grown, 20 acres must be non-Bt corn. For those in the more Southern growing areas of the cotton belt the Table 1 applies.

Problems with measuring costs and benefits of refuges

Bt cotton refuges have both benefits and costs to producers. However, the costs and benefits accrue over different time periods. The costs of refuges, forgone farm income, are incurred annually, while benefits of refuges from additional years of Bt cotton effectiveness may only be felt in later years. The costs of refuges are easier to measure. They can be inferred from estimates of net income benefits of Bt cotton. Estimates of income benefits are more directly observable and measurable and these have been published widely (Gianessi and Carpenter, 1999; Carpenter and Gianessi, 2001).

Benefits of refuges are difficult to measure for a number of reasons. First, they depend on when resistance occurs without a refuge. Second, they depend on how many years a refuge delays the onset of resistance. Third, it depends on producer and EPA responses to any resistance outbreaks. Fourth, it will depend on when second generation Bt cotton varieties become available, how effective they are, and how they are priced. There is a high degree of uncertainty surrounding all the factors.

The focus of this study is the 80:20 option and the 95:5 option. These are the most common options used by producers. Other options account for a minimal use by growers. The per hectare cost of the 80:20 sprayed option C_{80} is: $C_{80}=0.20\ (NI_B-NI_C)$ where NI_B =

Net Income on Bt acres and NI_C is Net Income on sprayed conventional acres. The equation shows that producers forego Bt cotton benefits on 20% of their total cotton acreage.

The per hectare costs of the 95:5 sprayed option C_{95} is: $C_{95}=0.05\ (NI_B - NI_U)$ where NI_B = Net Income on Bt acres and NI_U is Net Income on unsprayed refuge acres. The equation shows that producers forego Bt cotton benefits on 5% of their total cotton acreage. Unsprayed refuge yields and net returns are lower than yields and returns on conventional sprayed acreage. ($NI_U < NI_C < NI_B$). If growers are profit maximizers, they will only choose the 95:5 option if it yields greater returns than the 80:20 option. In this case, the cost of the 95:5 refuge requirement will be less than 20% of the net income gain from using Bt cotton.

Refuge requirements don't constrain all producers

In 2000, roughly 2.1 million hectares were planted to Bt cotton. Of these:

(a) 0.89 million (42%) were farmed under the 95-5 option, planting 95% Bt cotton,
(b) 0.44 million (21%) were farmed under the 80-20 option, planting 80% Bt cotton,
(c) 0.77 million (37%) were farmed under the 80-20 option but planted less than 80% Bt cotton.

For producers in category (c), accounting for 37% of all U.S. Bt cotton area, the current refuge requirements do not appear to constrain farm operations or impose costs on growers (Figure 1).

Why do so many producers forego planting all the Bt cotton that they are allowed to? One reason might be differences in expected pest pressure (and gains from using Bt cotton) across different farm fields. Another possible explanation for partial adoption is that producers may be risk averse, expected utility maximizers, who care both about the variance and mean of economic returns rather than just expected profits. Risk-averse farmers may be adopting Bt more to reduce the variability of income than to raise the average level of income (Figure 2).

What are the long-run net costs of current U.S. Bt cotton refuges?

We say "net costs" because it is possible for refuge requirements – while costly to individual growers in the short run – to increase grower returns collectively over the long run. This can happen if the long-run benefits (prolonged Bt effectiveness) outweigh annual costs. The first step to estimating the net costs of refuges is to estimate the present value of gross refuge costs over several years. Gross costs are the foregone income from following the refuge requirements. For operations not constrained by refuge requirements (farms accounting for 37% of Bt cotton area), these costs are zero. For the remaining 63%, gross costs are 20% (or less) of annual gains from using Bt cotton. Estimates of annual gains from Bt cotton vary widely across time and location, ranging from $0 to over $250 per hectare. Reported estimates of average national impacts for the U.S. range from $50 to $125 per hectare. This means the gross costs of refuge requirements are on the order $10 to $25 per hectare per year.

The next step is to estimate the benefits of additional years of Bt effectiveness. To do this, one needs to know (or make assumptions about):

(a) When resistance would occur without a refuge,
(b) How many additional years of Bt cotton effectiveness a given refuge provides,
(c) When growers can switch to second-generation Bt cotton varieties (not affected by any cross-resistance),
(d) What the cost of second-generation varieties will be, and
(e) Producer and regulator response to resistance outbreaks.

If one knew the answers to (a)-(e), estimating the long-run net costs of refuge requirements would then be straightforward. The problem, of course, is the high degree of scientific uncertainty about how fast target pests might develop resistance to Bt cotton and how refuges of particular sizes slow that development.

Using scenario analysis to address uncertainty

The strategic management literature advocates using scenarios to help decision-makers understand the future impacts of current decisions (Wack, 1985). A key to successful scenario analysis is limiting the alternatives provided to decision-makers. Usually, just two or three scenarios may be considered. Because there are often a large number of uncertain parameters to consider, scenarios will be more comparable and useful if they use consistent underlying assumptions. For this study we considered two scenarios to illustrate what plausible ranges are for the costs of refuge requirements and how better scientific information could improve these estimates.

Table 1 shows the common assumptions used for both scenarios and specific differences in assumptions between Scenario 1 and Scenario 2. Bt cotton is assumed to provide growers with benefits of $123.50/hectare ($50/acre). This combines benefits from higher yields and reduced costs of conventional insecticide applications, net of technology fees. In Scenario 1, growers can switch to second-generation Bt cotton varieties after year nine. Resistance would not have occurred within eight years, even without a refuge. The refuge requirement costs growers 20% of their per hectare Bt gain or $24.70 per hectare per year (Figure 3). In this scenario, refuges have no benefits and only impose costs. Scenario 1 thus represents the upper bound of the cost of refuge requirements.

In Scenario 2, resistance occurs by the seventh year of Bt cotton production (Figure 4). It is assumed that growers discontinue planting it, either because it is no longer profitable, or that the Environmental Protection Agency prohibits further planting. Implicitly, this scenario assumes that resistance is anticipated and Bt cotton is simply not planted. Costs of resistance would be higher if Bt cotton were planted and found ineffective at controlling target pests because of resistance. In this case, growers may apply more conventional insecticides, be required to plough down their crops, or both. We ignore these potential costs, in part for simplicity, but also in part because such costs may be covered by USDA crop insurance policies or disaster assistance payments. With the current U.S. refuge policy in place, Scenario 2 assumes that the refuges extend the life of Bt cotton from six to eight years. After that time, growers can shift to the second generation technology.

In Scenario 2, the refuge policy costs growers \$24.70/hectare in years one to six, but growers get two additional years of Bt cotton benefits \$98.80/hectare in both years seven and eight (where \$98.80= \$123.50 x 0.80). Averaged over eight years and using a 7% discount rate, the present value of grower returns are \$78.92/hectare/year under the refuge requirement and \$78.74/hectare/year without a refuge. In this case, producer returns are higher with the refuge requirement. This happens because grower benefits from two extra years of Bt cotton effectiveness outweigh the annual refuge costs over the long run. How likely is Scenario 2? This is uncertain, but Scenario 2 is a plausible scenario, based on existing entomological models of resistance development (U.S. EPA, 2000). In this case, refuges have clear benefits, along with costs.

Discussion

In Scenario 1, 80:20 – sprayed and 95:5 – unsprayed refuge requirements cost growers 20% of their annual per hectare gains from using Bt cotton. In the US, this 20% figure could average around \$10 - \$25 per hectare per year. In Scenario 2, refuge requirements are essentially costless to growers, averaged over an 8-year period. In sum, the specific U.S. refuge requirements considered cost at most \$25/hectare/year, but also quite possibly cost nothing, or actually increase farm returns. Better scientific information about the development of resistance would not change the upper bound estimate of \$25/hectare/year, but would provide information about whether average costs are closer to \$25 or to \$0.

Refuges may be thought of as an "insurance policy" against resistance, with the gross, annual cost of refuge requirements as an insurance premium. These estimates suggest that if, without refuges, widespread resistance to Bt cotton would have developed in the United States by the 2001 crop year, then the existing refuge requirements have "paid for themselves." In other words, if there otherwise had been widespread resistance by 2001, grower returns with refuge requirements would be greater than returns with no refuge regulations.

The methods employed here, could easily be applied to estimating upper bounds of alternative refuge regulations (e.g. different sizes, configurations). They could also be used to estimate upper bounds of refuge policies in other countries, even with limited data.

Conclusions

Using simple calculations with modest data requirements it is possible to estimate the gross, annual costs of different Bt cotton refuge policies. This approach could be readily applied in developing countries with data limitations. On nearly two thirds of U.S. Bt cotton area, refuge requirements were binding constraints. On this area, the gross, annual costs of were up to 20 percent of the annual per hectare gain from using Bt cotton. The 20 percent figure represents an upper bound on cost estimates. Given estimates of Bt cotton benefits, these costs could range from \$10-\$25 per hectare per year, depending on location and pest pressure. In the U.S., growers planting over a third of Bt cotton area, planted less Bt cotton than the maximum allowed under refuge requirements. For these growers, refuges requirements do not impose regulatory costs.

Partial adoption of Bt cotton raises questions for future research. First, one possible explanation for partial adoption is that producers may be risk averse, expected utility maximizers, who care both about the variance and mean of economic returns rather than just expected profits. Future work could examine the role of Bt cotton in managing farm yield and income risk. Second, the fact that regulations are binding for some producers, but not others implies that there is scope for further reducing regulatory costs through community refuge policies. This of course would require that those who find the requirements binding and those who do not would have to be in proximity to one another. Third, little is currently known about patterns of adoption of different refuge strategies, either across regions or by different producers within the same region. A better understanding of what factors affect refuge choice would provide better insights into the overall cost of refuge policies.

Refuge requirements are costly to individual growers in the short run, but can increase grower returns collectively in the long run. This can happen if the long-run benefits of refuges (prolonged Bt effectiveness) outweigh annual costs (foregone Bt benefits on refuge area). Would there have been pest resistance to Bt cotton by 2001 if U.S. refuge regulations had not been in place? We may never know with any certainty, but entomological studies suggest that this is quite plausible. If this would indeed have been the case, then the long-run costs of U.S. refuge policies to date will have been minimal. Thus, in areas where significant resistance would have occurred, leading to field failures and suspension of Bt cotton production by 2001 without a refuge, the refuge policy in place would have "paid for itself." We caution, however, that this conclusion compares standing refuge requirements with a "no refuge" alternative. It does not address the costs and benefits of expanding the size of current refuge requirements.

References

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Table 1. *Common assumptions and specific assumptions for Scenarios 1 and 2.*

Common assumptions for both scenarios

- gains from Bt cotton adoption are $123.50 / hectare / year (= $50 / acre / year)
- refuges reduce per acre Bt cotton gain by 20% per year
- growers can switch to "second generation" Bt cotton varieties after 9 years
- grower net returns under second generation varieties are equal to or better than returns using first generation varieties
- discount rate = 7%

Scenario 1

- resistance would not occur within 8 years, even without any refuge
- in this case, resistance is not a problem; refuges only impose costs on producers
- this represents an "upper bound" estimate of costs of refuges

Scenario 2

- without refuges, resistance occurs after 6 years
- once resistance occurs there is no net gain from Bt cotton adoption (this assumes that growers either anticipate that Bt cotton will no longer be more profitable than conventional cotton or that regulators prohibit its use after a resistance outbreak)

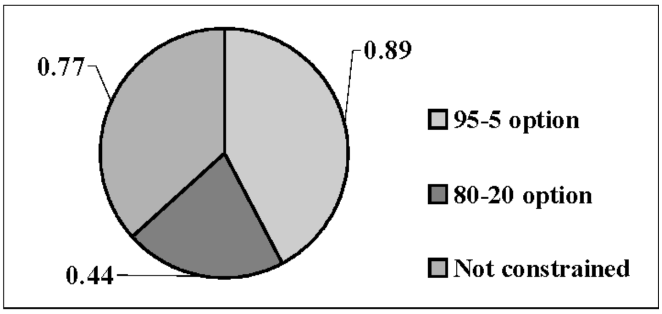

Figure 1. Bt cotton area in United States under different refuge regimes in 2000 in millions of hectares.

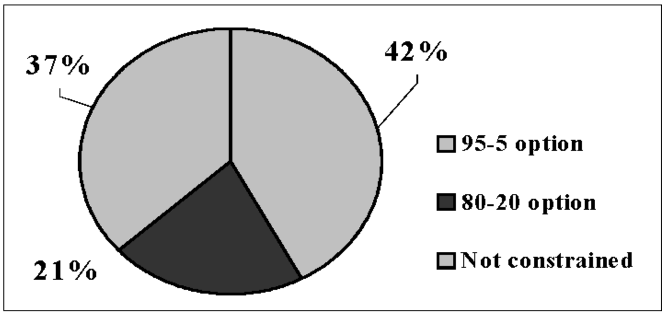

Figure 2. Percent of Bt cotton acres farmed under different refuge regimes in United States, 2000.

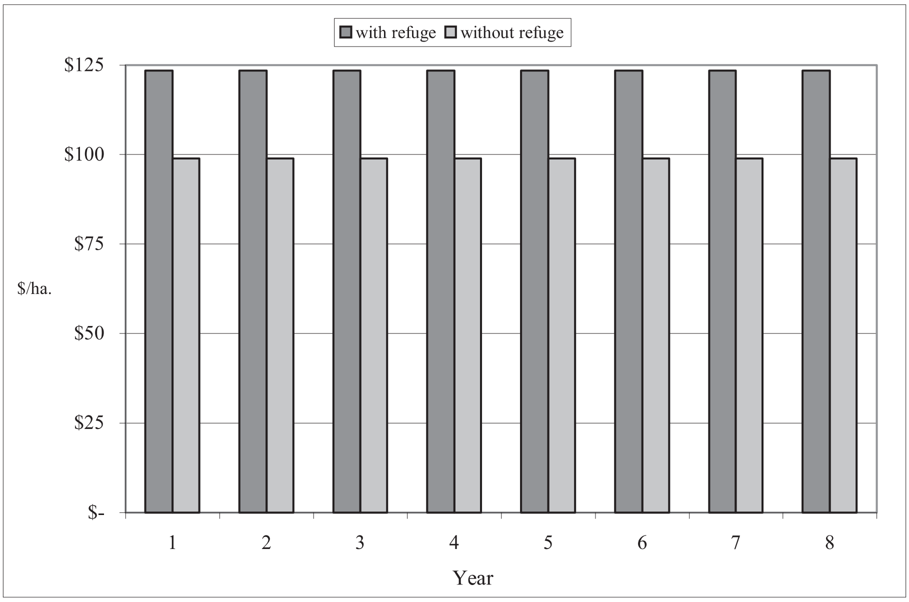

Figure 3. Scenario 1: Refuge reduces Bt gains by 20%; no resistance within 8 years.

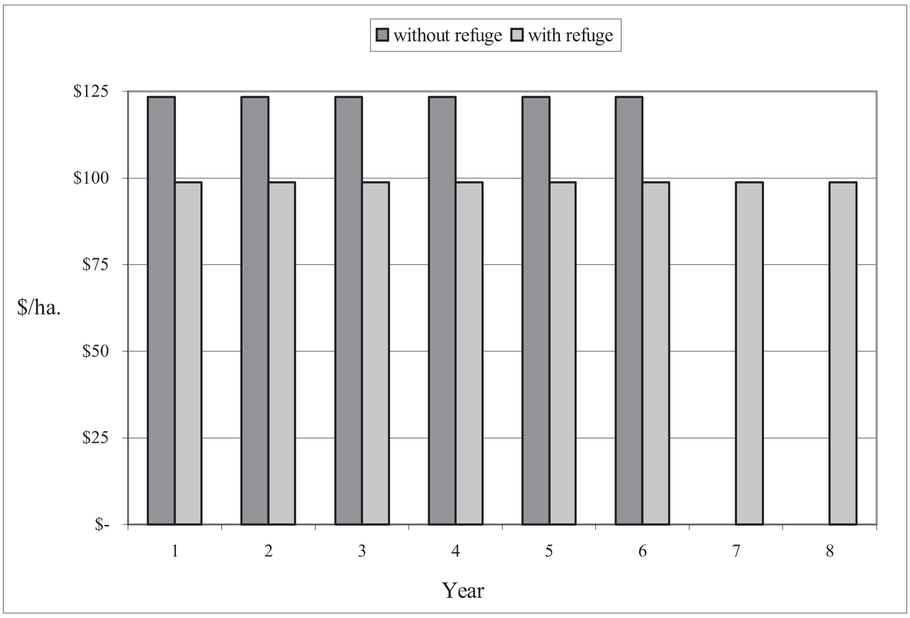

Figure 4. Scenario 2: Refuge policy pays for itself; resistance in 7th year.