Keeping One Row Ahead of the Bugs

THE ECONOMICS OF PEST RESISTANCE TO TRANSGENIC CROPS

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The fight against agricultural pests that destroy crops and reduce yields is as old as agriculture itself. In the 21st-century variant of this fight, humans have called in biotechnology. Some commercial varieties of corn, soybean, and cotton, among other crops, have now been engineered to express a protein of Bacillus thuringiensis (or Bt), a soil microbe that can kill caterpillars and other agricultural pests while being apparently harmless to humans and other nontarget species. Bt has been used in foliar sprays for more than four decades, mostly in organic farming. Now, with rapidly expanding acreage of Bt crops and widespread exposure of pests to the Bt toxin from commercial agriculture, resistant strains of pests may develop.

Resistance evolves in the following way. Initially, resistance genes occur at extremely low frequencies in the pest population because they are not essential to the species' survival. Once exposed to a pesticide, however, individual pests that do not possess the resistance gene are killed while the few with the gene survive. Over time and with repeated exposure to the toxin, the proportion of resistant pests becomes significant, reducing the effectiveness of the pesticide. This problem of resistance complicates any effort to control a biological organism through chemical or biochemical methods. This is particularly important in the case of pest-resistant transgenic crops: the rapidly expanding share of genetically modified (GM) crops in agriculture worldwide creates greater potential for systemwide damage if these crops fail against pests.

Economic Costs of Resistance

Since pest resistance to Bt has yet to be detected, the economic impact of resistance to Bt is not measurable. However, estimates for other pesticides may offer some indication of what could lie ahead. According to a recent article in *Science*, each year in the United States the cost of new pesticides to combat resistant pests runs about $1.2 billion, and the cost of pest damage to the food industry ranges between $2 billion and $7 billion. These cost estimates do not include environmental damages associated with increased pesticide use.

From a societal perspective, estimating the costs of pest control measures is further confounded by two additional factors that are external to the individual grower: increased use of Bt crops by any single grower engenders pest resistance, harming all growers, and use of these measures also reduces the pest population, which benefits all growers. Consequently, it is difficult to conclude simply from current levels of pest resistance whether past pesticide use has been optimal.

An important cost of resistance may come in the form of having to invent new technologies to replace those that are no longer effective. It is reported that developing a genetically modified Bt plant variety can take 6 to 12 years and cost $50–$300 million. However, without a proper assessment of the costs of resistance and the benefits of using Bt crops, it is difficult to assess whether the current rate at which technologies are being "depleted" is, from a societal perspective, efficient.

Refuge Strategies

In anticipation of the potential pest resistance to Bt technology, the U.S. Environmental Protection Agency (EPA) has required seed companies to ensure that farmers plant a certain proportion of their fields with a non-Bt variety (to provide a "refuge" where Bt-susceptible pests can survive). Refuges allow for interbreeding between pests that may have developed resistance to Bt and pests that remain susceptible to Bt but feed on the non-Bt crop (to dilute the resistance gene in the total population). Additionally, the strategy calls for a level of Bt toxin in the crop that is more than 25 times the concentration required to kill susceptible larvae (to make it difficult for the resistance gene to overcome the effect). Similar regulations have been imposed in Canada, which require that non-Bt corn be planted within a quarter-mile of the farthest Bt corn in a field.

In the past five years, the socially optimal refuge size and the current refuge requirements have been widely debated. While industry and farmer groups have argued for smaller non-Bt refuges than the currently mandated 20%, environmental groups are fighting for refuge requirements as large as 50% of cultivated acreage.

Current refuge requirements are based on fairly rigid assumptions: Bt crops dominate the marketplace and pests stay fixed in one locale. But when market penetration is assumed to be less than complete and pests are considered to be mobile, then non-Bt fields can operate as natural refuges for Bt-susceptible pests. In fact, high pest mobility and low market penetration can be substitutes in managing pest resistance, and when the rigid assumptions are relaxed, the optimal refuge level for Bt fields is considerably smaller than 20%.

The possibility that stringent refuge requirements could result in lower compliance also must be considered. Farmer

cooperation depends on the costs of growing an appropriately designed and sized refuge crop. One study from Kansas showed that the marginal cost of a 20% refuge requirement was fairly small. As one might expect, the cost to the farmer was greater for a 20% non-Bt (but sprayed) refuge, when compared with an unsprayed refuge of the same size.

Nevertheless, according to a survey by the National Corn Growers' Association, although 90% of farmers said they followed the rules in 2000, only 71% could accurately state the required sizes and locations of the refuges, suggesting that 29% may not have been in compliance. And with increased plantings of Bt corn, few natural non-Bt refuges may remain.

Incentives for Compliance

The challenge, then, is to design incentives that encourage farmers to invest in socially desirable refuge strategies. Several mechanisms may offer alternatives to mandatory refuges. For instance, a "resistance user fee" levied on GM seeds would make growers bear the social cost associated with pest resistance. This user fee could be calibrated to the density of Bt crops in the area and could be used to set up common refuge areas or be used to pay some farmers to grow only non-Bt crops. A similar option would allow growers to pool their non-Bt refuge areas or jointly pay a single farmer to grow only non-Bt crops as long as these refuges satisfy biological requirements for spatial proximity to the Bt crops. An alternative strategy may be to subsidize seed mixtures that contain both GM and non-GM varieties and may be suited to pests which tend not to move very much.

Yet another mechanism is one that uses tradable refuge "permits." The concept recalls tradable performance standards under the Clean Air Act and could be applied in areas of monoculture by fixing the maximum share of acreage that could be committed to Bt crops. Growers that focus on non-Bt crops would receive refuge permits that could then be bought by growers of Bt crops who don't plant their own refuges.

Ideally, refuge policies would encourage farmers to optimally manage for resistance on their farms. Large farmers, which suffer more of the resistance problems directly, may have a greater incentive to manage for resistance without external motivating factors than smaller farmers, since they may bear a relatively larger proportion of the burden of resistance that their farming practices may create. A survey of Bt corn growers in Ontario found that farmers living in areas of higher pest infestation were more likely to use Bt corn. Such areas are more likely to see resistance developing and consequently require greater adherence to resistance management strategies.

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Regulating a Monopoly?

Some economists, however, have questioned whether refuge regulations are required at all. Since Monsanto is a monopolistic owner of the Bt technology, it may have more incentive for ensuring that growers are scrupulous in planting refuges—thereby ensuring that their seed value is maintained—than if there were a competitive supply of GM seeds. Under certain conditions, this incentive may actually encourage an even greater level of effort on refuges than is socially optimal. That is, one would expect to see refuges being grown even if EPA did not mandate them because the seed company can ignore the cost of growing refuges as long as its customers can grow a profitable crop.

Recent theoretical research suggests that the level of care that Monsanto would exercise in the use of its Bt technology, relative to the socially optimal level of care, depends on the availability of future, alternative Bt technologies. If it had no backup technology available to replace the current one when it was exhausted, Monsanto would behave more conservatively than would government policymakers in ensuring that resistance management plans were implemented carefully. One could then argue for less regulatory stringency. However, if alternatives are being readied, Monsanto should be more likely to care less about resistance than policymakers and even be eager to move on to future revenue sources.

Innovation as a Response

The economic value of refuge strategies to society is largely determined by the availability of substitute technologies. The current pest control technology based on the Bt toxin, is it-

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self a replacement for older methods based on pyrethroids, which were becoming obsolete because of growing pest resistance. Firms that sell pest control compensate for this obsolescence by investing in research. In anticipation of resistance to today's Bt cotton, Monsanto has developed Bollgard II, which codes for two Bt proteins with different modes of action. The advantage of a "stacked" gene technology is that pests would have to develop resistance to two proteins, the probability of which is far lower than that of developing resistance to a single protein.

But can we count on the private sector to provide an adequate technological response to the resistance problem? Consider the case of resistance to antibiotics. For many years, physicians freely used the available antibiotics in the belief that pharmaceutical companies would continue to develop new ones. However, the widespread resistance to existing antibiotics increases the probability that any new drug will be ineffective shortly after its introduction, and this cross-resistance makes the return on investment risky. Although this does not yet appear to be the case for Bt crops, it may not be an unlikely scenario in the future.

Similarly, estimates of the resistance-related costs of withdrawing organophosphates from apple farming might be too low if there is significant cross-resistance between old and new pesticides. Moreover, the costs of introducing new pesticides have increased dramatically with each generation of pesticide.

The patent system, of course, is intended to encourage new technologies. When pesticide resistance is a recurring problem, however, a seed company faces two considerations that work in opposite directions. On the one hand, a product could be made obsolete by resistance if a firm sells too much, and on the other hand, it could be made obsolete by a competitor's new product before the firm has recovered the research costs. Under such circumstances, the standard patent duration of 17 years may be too short to give the firm sufficient incentive to care about resistance: its product will become obsolete regardless.

A final consideration is whether a firm that holds a monopoly would introduce sufficient variety in technologies to ensure that the selection pressure on any single technology does not result in rapid evolution of resistance. The monopolist must choose between introducing all GM crops up front, which would be socially beneficial, or staggering them, which has two advantages to the firm: it can engage in price discrimination through intentional obsolescence of the older technology, and it enjoys no reward for introducing variety—failure is actually the desired outcome because it forces customers to buy the next generation of seed. The way to get around this is to encourage innovation in new methods of pest control.

The value of new GM crops is lowered to the extent that resistance to current varieties implies more rapid evolution of resistance to new varieties. As with antibiotics and human health, a balanced approach between management of existing Bt technologies while searching for substitute technologies may be desirable. ■

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For More Information

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