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## Bt Crops Can Increase Yields Substantially in Developing Countries

by

*Matin Qaim and David Zilberman*

*Genetically modified cotton with Bt has a high yield effect in experimental plots in India. Although Bt cotton has been widely adopted in the United States, its impact on yields has been modest. This study shows that the high yield effect in India suggests that the technology can be of much value in developing countries.*

A debate continues concerning the use and future of genetically modified (GM) crop varieties. These varieties are costly to develop and their replication may entail environmental risk. Critics of these technologies argue that based on their past performance, their value to developing countries is limited because, thus far, applications of GM crops in the United States, China and Argentina have resulted in rather modest increases in yield. The main benefit from using GM varieties in the United States has been the reduction in the use of chemical pesticides, which has led to important economic and environmental gain. However, it has often been argued that GM crops have little to offer the poorest countries, where there is a need for increased local agricultural output on a limited amount of farmland.

We argue, herein, that this generalization is wrong, both on conceptual and empirical grounds. We first use basic principles of production economics to suggest that impacts of technologies may vary by location depending upon their economic and ecological conditions, and thus, GM varieties may have significant yield-increasing effects in developing countries, while having different effects

in developed countries. Then, using the example of Bt (*Bacillus thuringiensis*) cotton in India, we show that GM crops can have significant yield effects, which are most likely to occur in the developing world, especially in the tropics and sub-tropics. The evidence in India supports a general principle that a pest-control strategy, in this case biotechnology, has a strong yield effect in locations where the damage is substantial and alternative controls are not used.

### Pest Control as Damage Control Agents

A significant body of economic theory focuses on the economics of pest control. It models crop output as "potential output" (maximum output produced by labor and inputs such as water and fertilizers without pest damage) minus damage. Pest damage is the outcome of pest infestation, and the application and effectiveness of pest control such as chemical pesticides, biological controls, etc. Pest damage in some cases may reach 70 percent of potential output, if the climatic conditions support a large pest population, e.g., a humid climate and when pesticides are not applied or are ineffective. Some plant-breeding

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activities have increased potential output (maximum amount that can be produced without any damage). For example, Green Revolution dwarf wheat varieties sometimes doubled potential yields. Future applications of biotechnology aim to improve potential yields by, for example, increasing crop capacity to utilize water, including saline water. Thus far, the major applications of agricultural biotechnology have been pest-control related. They include both pest resistant varieties where Bt was inserted into cotton, corn and soybeans, and herbicide-resistant varieties, where, through genetic manipulation, plants tolerated applications of herbicides. While these GM varieties do not increase potential output, they may nevertheless increase actual output where pest damage has been substantial. In the case of the United States, in most crops, traditional pest control has limited yield losses up to 15-20 percent, and thus, the potential for yield gain through Bt is modest. Indeed, the main incentive to develop GM varieties was to reduce chemical pesticide use, and reduce cost of operation because of the simplicity of the technology. On the other hand, the theory suggests that in locations where pest damage is high and effective pest control cannot be used, the yield effect of GM varieties may be substantial. This hypothesis was tested in a case study of the yield effect of Bt cotton in India.

### The Case Study in India

Bt cotton provides a fairly high degree of resistance to the American bollworm (*Helicoverpa armigera*), the major insect pest in India. The technology was developed by Monsanto and was introduced into several Indian hybrids in collaboration with the Maharashtra Hybrid Seed Company (Mahyco). Field trials with these Bt hybrids have been carried out since 1997 and, for the 2002/03 growing season, the technology was commercially approved by the Indian authorities. Its performance during the first commercial season in India is hotly disputed among biotechnology advocates and opponents, but an independent scientific assessment has not been carried out so far.

For our analysis, we used data from on-farm field trials that were carried out during the 2001/02 growing season as part of the regulatory procedure. On 157 farms in three different states, Bt cotton hybrids were planted next to an isogenic line without the Bt gene and a local hybrid commonly grown in the

particular district. All three plots were managed by the farmers themselves, following customary practices. Apart from official data that were collected by local researchers for biosafety evaluation, we used our own questionnaire to obtain details on input-output relationships from participating farmers.

While there was no significant difference in the number of sprays against sucking pests, Bt hybrids were sprayed three times less often against bollworms than the conventional hybrids. On average, insecticide amounts on Bt cotton plots were reduced by almost 70 percent, which is consistent with studies from other countries. The difference in India, however, is that Bt cotton also led to a significant yield effect. During the field trials, average yields of Bt hybrids exceeded those of non-Bt counterparts 80 percent and 87 percent, respectively.

The results in India are consistent with our theoretical construct that the gain in yield associated with the use of Bt is because of the avoided crop losses. Under Indian conditions, bollworms have a high destructive capacity, which is not well controlled in conventional cotton. At average pesticide amounts of 1.6 kg/ha (active ingredients) on the conventional trial plots, crop damage in 2001/02 was about 60 percent. Bt does not completely eliminate pest-related yield losses. Yet, to achieve the same level of damage control without the technology would require a tripling of currently used pesticide quantities.

The 2001/02 season had high bollworm pressure in India, so that average yield effects will be somewhat lower in years with less pest problems. Moreover, although the trials were managed by farmers, experimental results cannot simply be extrapolated to commercial agriculture. But even when discounting for these aspects, yield advantages of Bt cotton will remain bigger in India than in the United States or China.

Analysis of factors influencing yield impacts of new, effective pest control technologies suggests that they depend on local pest pressure, availability of alternatives for pest control and farmers' adoption of these alternatives. Generally, pest pressure in tropical and sub-tropical regions is higher than in temperate zones, while pesticide-use intensities are much lower, due to technical and economic constraints. In India, pesticides are available on local markets, but their effectiveness is limited

Bt - Continued on page 11

# Determining the Minimum Acreage for Cost-Effective Adoption of Auto-Guidance Systems in Cotton Production

by

*M. Hope Lewis*

*New agricultural technologies require increased initial investment but tend to decrease variable costs. This article analyzes the minimum acreage needed to adopt auto-guidance technology in cotton production.*

With the advent of geographical information systems technology and the availability of global positioning system information to the agricultural sectors, new opportunities in site-specific crop management have become available. One of the most exciting is the new generation of auto-guidance equipment. At a minimum, such systems implement a complex structure of satellites, base stations and portable receiver “rover” units.

In a market dominated by users of conventional technology, such as the market for cotton, an early adopter of a system that reduces marginal cost will experience above-average operating profits in the short run. Such equipment can decrease inputs while increasing output; as more producers adopt the new technology, supply will expand and price will drop. Any profit-maximizing producer must stay abreast of cost-effective technology to remain competitive.

However, not all farms can reasonably expect to benefit from this technology. The purchase of capital such as Real-Time Kinetics Global Positioning System (RTK GPS) receivers and base stations, computer systems and software, potentiometers and hydraulic steering devices, total in the tens of thousands of dollars. Benefits from lower variable costs and higher output can exceed the fixed expense when the technology is used on a farm of sufficient acreage. Before implementation, a cotton farmer needs to know if his farm is large enough to benefit from the technology. An awareness of the minimum cost-effective acreage for new technology is essential to farmers and farm advisors. This article provides a method to determine the minimum cost-effective acreage for use of auto-guided tractors in farming cotton.

## **Auto-Guidance Technology**

Auto-guidance systems are wholly dependent on GPS technology, which requires a base station

located on or near the farm, a rover unit for each tractor, a computer and its software. These systems receive a satellite signal every few seconds and employ base station correction signals to improve satellite signal accuracy. The high level of accuracy will allow a great deal of secondary implementation. The uses of the systems go well beyond auto-guidance. This technology is well-suited to cotton production, which requires many cultural practices, including subsoiling, disking, landplaning, bedding, weed control, seeding, fertilizing, irrigating, harvesting, and applying pesticides, growth regulators and defoliators. A farmer with some experience using the computer systems can easily take soil samples, establish drip irrigation, apply material in variable rates and monitor crop yield without another substantial capital expenditure.

The system eliminates human error, such as overlapping and skipping that can lead to excessive or deficient applications of pesticides and fertilizers. A couple of inches skipped per row during bedding can accumulate too many rows per field, resulting in loss of revenue. The main disadvantages of auto-guidance systems include greater capital costs and maintenance and repair expenses. In addition, the value of time expended to learn how to use the system must also be considered. Each component of the system requires significant capital investment and has a limited expected useful life.

The most important advantage is that an auto-guidance system does not require the operator to see, so operations can run at night and in adverse weather conditions. This reduces the time period needed to perform each operation, therefore eliminating bottlenecks and allowing greater outputs to be gleaned from fewer inputs. For example, herbicides such as Staple™ need to be applied within a small window of time; enabling a tractor to run longer hours means that fewer days are needed to apply this type of product to a given area. These



*Any profit-maximizing producer must remain abreast of cost-effective technology to stay competitive. This producer uses GPS guided planting.*

*Photo by Shrini K. Upadhyaya,  
UC Davis, Department of Biological and Agricultural Engineering*

advantages and disadvantages can weigh heavily depending on the size of the operation. A small operation will be more affected by the high capital expenditure required and less able to reap the benefits of the advantages afforded by the technology.

In addition to understanding the mechanisms of cotton production and the advantages and disadvantages of auto-guidance systems, it is important also to note that there are many auto-guidance systems available. The one we will study involves a hydraulic steering mechanism which draws parallel passes in a field, but uses a lightbar that the operator must watch to navigate the turnarounds.

Vigorous competition between companies such as John Deere, Inc., Trimble and Beeline Technologies ensures that any profitability in the market will lead to continued research and development. The technology will become less expensive, easier to use and more accessible. At least one company has begun development of virtual reference systems via cellular channels—a step toward reducing costs by eliminating the need for a base station.

### Model Framework

Much of our data is taken from the 2002 Sacramento Valley Sample Cost of Production Study for cotton. If the model is applied to any other area, crop or time frame, numbers such as average yield, pesticide expenses, labor costs and market prices will have to be adjusted. We make the following assumptions:

- ❖ Hourly conventional laborer's wage totals \$10.39 after employer's share of payroll taxes. This figure is increased by five percent to \$10.90 for workers using auto-guidance equipment.
- ❖ Per-acre fuel, lube, maintenance and repair costs are based on use of one diesel-powered 215-hp crawler and one diesel-powered 130-hp four-wheel drive tractor.
- ❖ Each farmer custom hires a harvester and module builder; these costs are identical for either technology and will not be included in the model.
- ❖ There is no opportunity to purchase used equipment; all purchases related to the auto-guidance system will be considered new.

❖ The life of the system is capped at five years due to computer obsolescence and compatibility problems. After this time, the tractor can be retained but new computer equipment, software, GPS receivers, etc., must be purchased. Thus, there is no salvage value.

❖ Fixed costs incurred in both the conventional and auto-guidance technologies are offset and thus not included in the model.

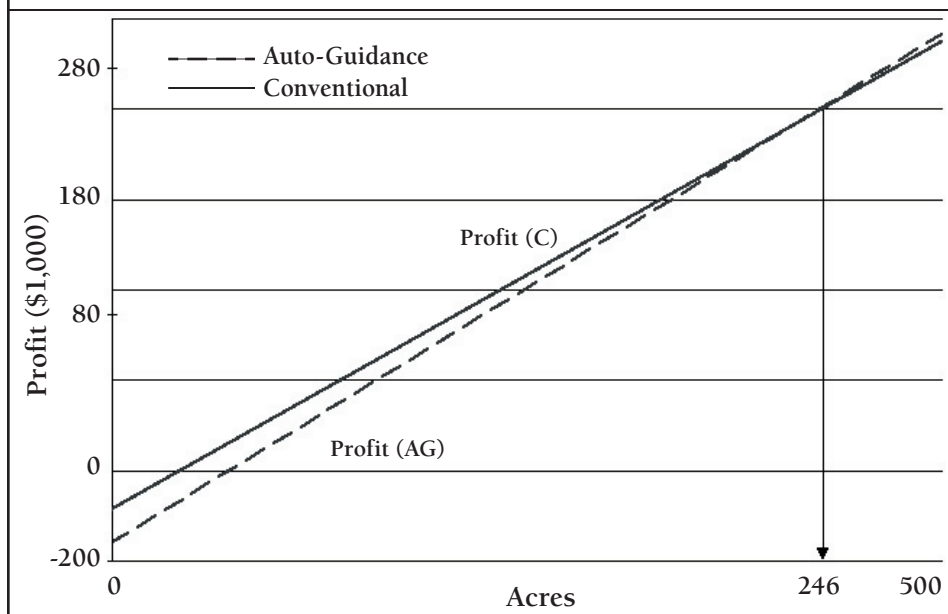
❖ All farms pay the same interest costs on their capital investments; this term will not be included in the model.

In the following equations, the subscripts "AG" and "C" will denote auto-guidance and conventional techniques, respectively. Where the variable profit lines are equal, the land activity will be at the "breakeven" acreage for the C and AG technologies. Farms with acreage greater than the breakeven level will benefit from adopting the AG technology, while smaller farmers are better off retaining the C technology. Total revenue (TR) is equal to market price multiplied by (lbs/acre) and number of acres and is the sum from total sales of lint and sales of seed. The revenue from the seed yield is a credit obtained from the ginner at harvest time.

$$TR_{AG} = \{[\text{lint}\$/\text{lb} * \text{Yield}_{AG}] + [\text{seed}\$/\text{lb} * \text{SeedYield}_{AG}]\} \\ * \text{land (acres)}$$

$$TR_C = \{[\text{lint}\$/\text{lb} * \text{Yield}_C] + [\text{seed}\$/\text{lb} * \text{SeedYield}_C]\} \\ * \text{land (acres)}$$

**Figure 1. Profit Comparison for Cotton: Auto-Guidance vs. Conventional Technology, Assuming 5% Yield Gain to Auto-Guidance**



❖ “w” is the cost of labor per hour; laborers on an auto-guidance system are assumed to make five percent greater wage than those on a conventional system.

❖ M is the cost of materials applied per acre.

❖ Ginning costs are \$0.0535/lb. of lint.

❖ Ginning credits are \$0.07/lb. of seed.

❖ “F” is the cost of fuel, lube, maintenance and repair per acre; this is the same for both techniques.

Both lint yield and seed yield (lbs/acre) using auto-guidance are generally slightly higher than yields using conventional techniques due to reduction in overlapping and skipping. These percent yield increments are denoted by  $\alpha$  and  $\beta$ , respectively.

$$\text{Yield}_{AG} = (1 + \alpha) * \text{Yield}_C = (1 + \alpha) * 1,250 \text{ lbs/ac}$$

$$\begin{aligned} \text{SeedYield}_{AG} &= (1 + \beta) * \text{SeedYield}_C \\ &= (1 + \beta) * 2,300 \text{ lbs/ac} \end{aligned}$$

Fixed costs for auto-guidance systems include:

- ❖ Base Station: \$20,000
- ❖ Two tractors with necessary equipment: \$15,000 each
- ❖ Computer system and software: \$3,000
- ❖ Annual GPS subscription: \$800
- ❖ Total: \$57,000

Conventional farming incurs none of these capital costs.

Variable costs are more complicated. Per-acre data such as fuel and lube, maintenance and repair, rental rates and material costs are taken from the cost of production study mentioned earlier.

The costs are the aggregation of average time spent per acre, cost of labor per hour, cost of materials per acre and other operational costs, for each of fifteen operations.

$$\text{Variable Costs}_{AG} = \text{land (acres)} * [ \{ (\text{man-hrs/acre})_{AG} * (w_C * 1.05) + M_{AG} + F \} + (\text{Yield}_{AG} * \$0.0535) ]$$

$$\text{Variable Costs}_C = \text{land (acres)} * [ \{ (\text{man-hrs/acre})_C * w_C + M_C + F \} + (\text{Yield}_C * \$0.0535) ]$$

Inputting the data from the 2002 Sacramento Valley Sample Costs of Production Study yields the following expressions for variable cost (VC) per acre:

$$\text{AG: } [ \{ (\text{man-hrs/acre})_{AG} * (w_C * 1.05) \} + M_{AG} + F ] = \$263.10$$

$$\text{C: } [ \{ (\text{man-hrs/acre})_C * w_C \} + M_C + F ] = \$273.94$$

$$\text{VC}_{AG} = \text{land (acres)} * [ \$263.10 + (\text{Yield}_{AG} * \$0.0535) ]$$

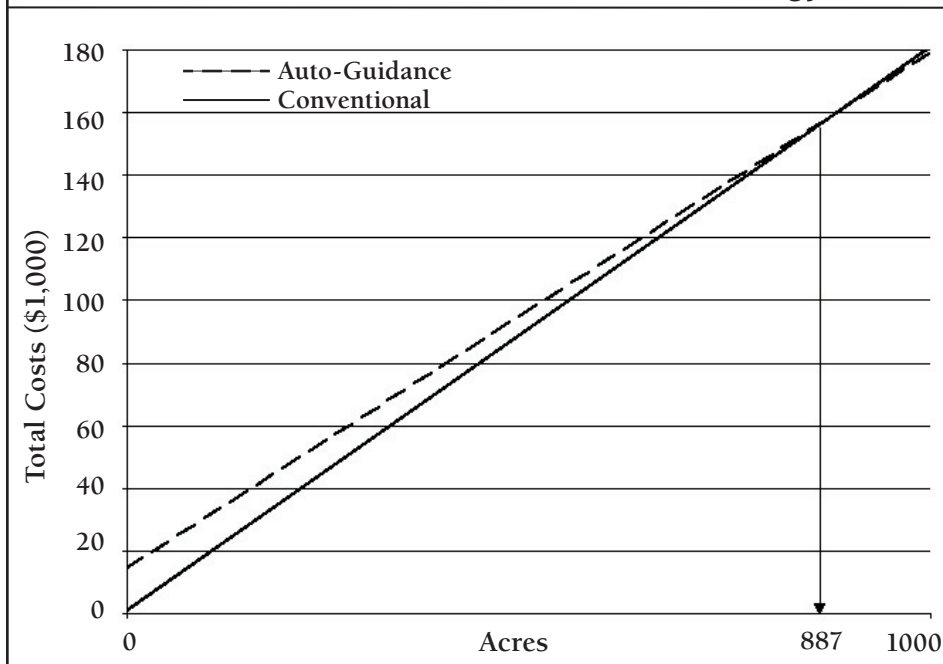
$$\text{VC}_C = \text{land (acres)} * [ \$273.94 + (\text{Yield}_C * \$0.0535) ]$$

The 2002 Sacramento Valley Sample Costs of Production Study reports the average market price as \$0.65 per pound; yield as 1,250 pounds of lint per acre and 2,300 pounds of seed per acre, using conventional technology. Yield using auto-guidance is assumed to be five percent greater in both cases: 1,312.5 and 2,415 pounds per acre, respectively.

$$\begin{aligned} \text{VC}_{AG} &= \text{land (acres)} * [ \$263.10 + \$70.22 ] \\ &= \$333.32 * \text{land (acres)} \end{aligned}$$

$$\begin{aligned} \text{VC}_C &= \text{land (acres)} * [ \$273.94 + \$66.88 ] \\ &= \$340.82 * \text{land (acres)} \end{aligned}$$

**Figure 2. Cost Comparison for Cotton:  
Auto-Guidance versus Conventional Technology**



technology, assuming the current parameters and variables. If the increased lint and seed yields from AG technology are ignored, the minimum farm size required to adopt an auto-guidance system is 887 acres (Figure 2). This latter figure seems more consistent with current adoption patterns. This outcome may be explained by short-term inefficiencies in learning and using the technology.

### Conclusion

For farms of sufficient size, the implementation of an auto-guidance system will reduce inputs while

Combining this information results in the following expression, in which we allow land to vary and equate the two variable profit equations to find the breakeven acreage to adopt the auto-guidance and conventional technology.

$$\begin{aligned} & [ \{ (\$0.65/\text{lb} * 1,312.5 \text{ lbs/acre}) + (\$0.07/\text{lb} * \\ & 2,415 \text{ lbs/acre}) \} * \text{land(aces)} ] - FC_{AG} - VC_{AG} \\ & = [ \{ (\$0.65/\text{lb} * 1,250 \text{ lbs/acre}) + (\$0.07/\text{lb} * 2,300\text{lbs}/ \\ & \text{acre}) \} * \text{land(aces)} ] - FC_C - VC_C \end{aligned}$$

where:

$$\begin{aligned} FC_{AG} &= (\$57,000 \text{ at } 7\% \text{ interest, } 5 \text{ years}) \\ &= \$13,794/\text{year} \end{aligned}$$

$$FC_C = \$0$$

$$VC_{AG} = \text{land (acres)} * \$333.32$$

$$VC_C = \text{land (acres)} * \$340.82$$

This model is very flexible in the case that new data are introduced. New parameters  $\alpha$  and  $\beta$ , different market prices for cotton, ginning costs and credits, material cost savings due to technological improvements and auto-guidance laborers' wage premium all can be easily inputted without changing the basic form of the model.

The variable profits are equal at 246 acres of land planted to cotton (Figure 1). This number is the minimum breakeven acreage to adopt AG

increasing yield, resulting in increased profits for those farmers who employ the technology ahead of their competitors. Analysis based upon a linear programming model reveals a breakeven acreage of 246 acres for the revenue and cost parameters defined in the model. If these parameters were to change, the breakeven acreage would change accordingly. This model can be adapted to calculate the same information for a different crop.

A decrease in marginal production costs increases the supply of cotton, increasing both producer and consumer welfare. This welfare increase depends on the share of cotton in the total economy and the percent of cotton acreage farmed using auto-guidance systems but, ultimately, the appropriate implementation of such technology benefits the economy in its entirety.

The 2002 Sacramento Valley Sample Costs of Production Study for cotton is among over 125 studies available for downloading in pdf format from the UC Davis Department of Agricultural and Resource Economics Web site at: [www.coststudies.ucdavis.edu](http://www.coststudies.ucdavis.edu)

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# The Economic Impacts of Critical Habitat Designation

by

**David Sunding**

*Designation of critical habitat can impose significant costs by raising the cost of development, reducing the amount of usable land and delaying completion of projects. These costs are borne by many groups including farmers, land owners, developers and, especially, consumers.*

Among environmental regulations, the Endangered Species Act has the most potential to alarm landowners and developers who fear its ability to slow or thwart implementation of their plans. In general, the requirements that the Act places on property owners are absolute and there is no role for economic analysis or a balancing of competing social objectives. One exception, however, is in the designation of critical habitat—an issue of great concern in California since literally millions of acres in the state have been so designated.

When the government deems that a species is endangered or threatened, it is also supposed to designate critical habitat, which includes the areas presently occupied by the species and other areas that are “essential to the conservation of the species” and which may require special management or protection. As Table 1 indicates, there are a large number of endangered species listed by the U.S. Fish and Wildlife Service (USFWS) so that the critical habitat designation process has the potential to affect a significantly large number of landowners.

Section 4 of the Endangered Species Act requires economic analysis of the impacts of critical habitat designation and authorizes the Secretary of the Interior to take these impacts into account when deciding whether to exclude land from critical habitat. In a recent study conducted with David Zilberman, I developed a framework for measuring such impacts that draws on stylized facts about project development and land conversion, and compared this method to the one used currently by the USFWS.

The most obvious economic effects of critical habitat designation (CHD) are to increase the cost of development by making it more difficult to obtain necessary permits and to reduce the size of individual projects (e.g., number of single-family housing units, office spaces, etc.). However, the economic effects of CHD go well beyond these costs. The process of land development is complex

and conditioned by numerous factors. If land is set aside or if the scale of projects is reduced by CHD, there may well be market and regional effects from this designation. Other land cannot necessarily be brought into production to make up for losses due to designation, and even if it can, it may be in a sub-optimal location. CHD also delays the development process, which imposes additional costs on developers, consumers and others in the affected region.

## The Numerous Impacts of Critical Habitat Designation

*Costs of Completing a Section 7 Consultation.* Section 7 of the Endangered Species Act requires federal agencies to consult with the USFWS to

**Table 1. Type and Number of Endangered Animal and Plant Species in the U.S.**

Mammals	65
Birds	78
Reptiles	14
Amphibians	12
Fishes	71
Clams	62
Snails	21
Insects	35
Arachnids	12
Crustaceans	18
Flowering Plants	570
Conifers and Cycads	2
Ferns and Allies	24
Lichens	2

*Source: U.S. Fish and Wildlife Service as of January 24, 2003*



insure that any activity funded, carried out or authorized will not likely jeopardize the continued existence of the species. This requirement increases the cost to complete the project and also imposes additional costs on federal agencies involved with the consultation. Sources of cost to the applicant include hiring outside consultants and attorneys to assist with the consultation process, and also the developer's own staff resources.

Another direct cost of Section 7 consultation is that the Service may require additional mitigation above that required by the action agency. In the case of California vernal pools, for example, the Service required that three acres of vernal pools be created for every one filled over and above the baseline. Adding the costs of the Section 7 consultation to the costs of mitigation, the direct, out-of-pocket cost of Section 7 consultation can be substantial, running to several thousand dollars per house in the case of some single-family housing projects.

***Costs of Project Modification.***

The Section 7 consultation process may also force project developers to redesign their project to avoid modification of certain areas deemed to be critical habitat. This project redesign typically reduces the output of the project. Again using the vernal pool case as an example, additional Section 7 conservation requirements consist of avoidance of 85.7 percent of vernal pools, a condition that allows only 14.3 percent of the project site to be developed. Project redesign imposes additional costs on developers and has other, potentially large, economic impacts that stem from the attendant reduction in output, particularly in areas like California that have a well-documented shortage of housing and urban infrastructure.

***Increase in Price and Reduction in the Availability of Housing and Other Development.*** Because critical habitat designation increases the cost of development and reduces the level of project output, it has the potential to alter regional markets for housing, commercial space and other types of development. In particular, critical habitat designation can increase market prices for these goods and result in large losses to consumers.

Whether for homes, schools or other activities, there are numerous physical and regulatory constraints on site selection. Accordingly, if critical habitat designation places some land off-limits to development, there are a limited number of comparable sites that can be developed to pick up the slack. While an area may appear to have an ample supply of developable land, in reality the development process is highly constrained. In such a setting, critical habitat designation can reduce the regional stock of housing and other goods, and prices of these goods will increase to establish new market equilibria.

***Delay in Completion of Projects.*** Critical habitat designation can also delay completion of projects. Unlike the supply-reduction effects just described, delay is a pure loss affecting both producers and consumers. Theoretical results suggest that in many cases delay can be the largest component of overall economic impact resulting from environmental regulation.

Delay affects project developers by pushing out project receipts further into the future. Delay affects consumers in that they must postpone the enjoyment of the project output. For example, if the project is to construct a school, then parents and children must wait to use the new facilities; if the project is to construct new homes, then homeowners must live temporarily in a less-than-optimal location, perhaps having to commute longer distances during this waiting period.

**Economic Losses  
Borne Primarily by Consumers**

The economic impacts of critical habitat designation are borne mainly by consumers. Cost increases can be passed on to consumers to some degree, and increases in market price of project outputs actually benefit producers.

A stylized example can help to provide some sense of the magnitude of impacts and their distribution across the affected population. Consider a 1,000-unit housing project to be built on 200 acres (an average of five homes per acre, including roads, open spaces and other infrastructure). The pre-regulation price of the homes in the project is

***“The economic impacts of critical habitat designation are borne mainly by consumers.”***

\$250,000, and the price elasticity of demand for these homes is  $-1.67$ . The pre-regulation marginal cost of homes in the project is assumed to be a constant \$200,000. Suppose that some of the project is considered to be critical habitat; development is to be avoided in these areas and any habitat impacts mitigated by some ratio of the USFWS's choosing. Suppose that the out-of-pocket cost to the developer of the Section 7 consultation, including the mitigation exaction, is \$2,000 per home. Suppose also that critical habitat designation reduces the size of the project to a total of 900 units instead of the planned 1,000. Finally, suppose that critical habitat concerns delay completion of the project by two years.

Based on these figures, what are the economic impacts of critical habitat designation for this hypothetical project? Homes in the project are now more expensive to construct and there are fewer of them, so their market price will increase. Under the assumptions above, the price of a home in the project will increase from \$250,000 to \$265,000.

Consumers lose from critical habitat designation in three ways. Some are unable to purchase homes at all due to the reduction in the size of the project. Some do purchase homes, but at higher prices. And what consumption does occur is two years later than it would have been without the critical habitat designation. The impacts on developers (and landowners) are more complex. While producers gain from the increase in home prices, they lose from the increase in costs and from the delay in completing the project and receiving their return on investment.

Taking consumers and producers together, the total economic losses from critical habitat designation are \$19.5 million for this project. This figure counts the cost of project delay, which amounts to \$12.5 million, or over half of total losses. While the designation reduces the size of the project from 1,000 to 900 completed units (which results mainly in losses to consumers), both consumers and producers must wait an extra two years for these 900 units to be completed.

Several interesting conclusions emerge from this example:

- ❖ Critical habitat designation can be quite expensive. Total economic losses amount to nearly \$20 million in the example, which implies costs of \$1 million per acre of habitat conserved.

- ❖ Consumers bear the brunt of losses from critical habitat designation. They are unambiguously harmed by increases in price and reductions in the number of homes available for purchase. Developers and landowners fare better because they can pass on some costs to consumers in the form of higher prices.

- ❖ Traditional measures of the cost of regulation, namely the out-of-pocket cost of Section 7 consultation, are far off the mark. In this example, they understate true impacts by more than 90 percent.

### **Regional and Indirect Impacts: Is Conservation Good for the Environment?**

Critical habitat designation is effectively an ad hoc tax on development that changes its intensity, location and timing. As such, critical habitat designation can literally change the shape of urban areas, and another class of economic impacts results.

A natural question to ask is whether, by limiting growth in certain areas, critical habitat designation pushes development to areas more distant from the city center, away from jobs, shopping areas, schools and other amenities. If the effect of critical habitat designation is to force relocation to areas further out on the urban fringe, there can be some important regional and indirect consequences of designation as well. For example, if critical habitat designation forces commuters to locate further from their jobs, then designation may increase traffic congestion and commute times, and may contribute to regional problems of sprawl and air pollution.

### **Impacts Beyond the Federal Nexus**

A common claim of the USFWS is that critical habitat designation only causes economic impacts in the presence of a federal nexus, that is if the activity in question is carried out with a federal permit or federal funding. While there is no definitive research on this topic, my work with developers, local government officials and others suggests that critical habitat designation has more far-reaching implications.

One concern is that development is subject to numerous regulatory processes carried out by federal, state and local authorities. If land is designated as critical habitat by the Service, this designation may affect the way the project is treated by other agencies through a "signaling" effect.

At a conceptual level, this signaling effect is not surprising. Regulators operate under uncertainty and are generally risk-averse. A decision by an expert environmental agency like the Service raises concerns about potential environmental impacts of the project and will lead other permitting agencies to take a more conservative approach to it. From a practical point of view, this signaling effect means that the costs of critical habitat designation go beyond the cost and the outcome of the Section 7 consultation process.

Another concern is that designation of critical habitat can impose costs on developers even if their project is not on critical habitat at all. The USFWS defines critical habitat in such a way that some time and expense is needed to determine whether a parcel is actually included or not. For example, critical habitat is defined in terms of landscape features and some investigation is required to determine their presence or absence on a particular parcel. Again, the practical effect is for the costs of critical habitat designation to extend beyond the Section 7 process.

### **Flaws in the Service's Approach to Economic Analysis**

It is useful to compare the types of economic impacts just described with those categorized in the Service's analyses of various critical habitat designations. There are two major failings in the Service's approach. First, the Service emphasizes only the most obvious aspects of cost, namely the direct, out-of-pocket expenditures needed to complete the Section 7 process, and ignores the potential for regional market impacts. Accordingly, the Service ascribes all economic impacts to developers and landowners and none to consumers who will, in fact, ultimately bear most of the costs for the reasons just indicated. Thus, the Service seriously underestimates the impacts of critical habitat designation (in some cases by more than 90 percent) and also mischaracterizes their incidence.

A more basic failing of the Service's approach is that it only purports to measure the aggregate economic impacts of a proposed designation. Congress intended that economic analysis be used to help prioritize land for inclusion in critical habitat. An analysis of the total cost of designation does not help determine which parcels should be included in critical habitat and which should be

excluded. What is needed instead is a more detailed approach to economic analysis that recognizes well-known differences in the opportunity cost of land.

### **Conclusion**

Critical habitat designation is an unusual part of the Environmental Safety Act in that the government is actually required to conduct an economic assessment of its impacts. With other provisions such as the listing of a species as threatened or endangered, for example, the Fish and Wildlife Service is forbidden from considering economic factors when making its decision. Congress' intent in this regard was not to use economic factors in deciding whether or not a species should be protected, but rather to balance economic and biological considerations in determining the specific geographic areas in which protection should occur.

It should also be noted that several critical habitat designations have been overturned by federal courts due to the inadequacy of the government's economic analysis. Accordingly, it is useful to compare the types of economic impacts just described with the method used by the Service in its previous analyses of economic impacts of critical habitat designation.

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Bt - Continued from page 2  
because bollworms have developed resistance to many of the common products. Furthermore, small-scale cotton producers are often credit-constrained and do not have access to chemicals at the necessary point in time.

The high yield effect of Bt cotton makes this technology especially appealing to the small farmers in India. Even though the likely prices of the GM hybrids are higher than the traditional cotton hybrids because of the yield effect, we expect profit to increase five-fold with the adoption. The profit gain may be smaller in years with lower pest infestation and lower cotton prices, yet clearly Bt cotton seems extremely attractive for the Indian grower at the present.

### Conclusion

Our finding for the case of Bt cotton in India, confirms our theoretical prediction and is likely to be more representative of GM crop impacts in developing countries than predictions based on the performance of Bt cotton in the United States and China. Table 1 generalizes our theory and suggests that the impact of Bt on crop yield varies by location. The table also reflects the pest pressure, and the availability and use of alternative pest control in varying locations.

Almost all GM crop technologies were initiated by commercial firms in the industrialized world, targeting the needs of farmers who are able to pay for them. Some varieties were transferred to the commercial sectors of Latin America and China, where agroecological conditions and pesticide application rates are similar. In all cases, yield effects have been low to medium, while there have been significant gains from pesticide substitution.

However, with careful adaptation and effective regulation, these same technologies can also be introduced to other developing-country regions, where yield effects will be more pronounced. Pest-resistant GM crops are easy to manage at the farm

**Table 1. Expected Yield Effects of Pest-Resistant GM Crops in Different Regions**

Region	Pest pressure	Availability of chemical alternatives	Adoption of chemical alternatives	Yield effect of GM crops
Developed countries	low to medium	high	high	low
Latin America (commercial)	medium	medium	high	low to medium
China	medium	medium	high	low to medium
Latin America (non-commercial)	medium	low to medium	low	medium to high
South and Southeast Asia	high	low to medium	low to medium	high
Africa	high	low	low	high

level, and they could substantially reduce current gaps between attainable and actual yields, especially in smallholder farming systems. Preliminary evidence from Indonesia and South Africa is in line with this hypothesis. For example, there is a 40 percent reported yield increase associated with the use of Bt cotton by small farmers in South Africa. Agricultural biotechnology offers many more applications for developing countries beyond pest control, but we show that the GM crops developed thus far can already have significant impacts. It is a major policy challenge to invest more in public research and address the existing institutional constraints, so that promising biotechnologies can reach the poor at affordable prices on a larger scale.

A more detailed article about this research has been published by M. Qaim and D. Zilberman in *Science*, Vol. 299 (7 February 2003), pp. 900-902.

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