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The Economic Impact of Genetically Engineered Crops

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Since the 1990s, genetic plant engineering has yielded a variety of applications for agricultural production, including traits intended to improve the shelf-life of produce, improve crop nitrogen fixation, and bolster control of agricultural pests. However, only two traits achieved commercial success. One trait confers insect resistance (IR) to crops by programming the crop plant to produce a naturally occurring chemical that is toxic to common insects. The other trait confers herbicide-tolerance (HT) and permits farmers to spray broad-spectrum chemicals to kill weeds without killing the crop plant. These traits have been widely adopted in production of corn, canola, cotton, and soybean.

The adoption of genetically engineered (GE) crops has significantly affected the economics of these crops and the welfare of farmers and consumers. It has also had spillover effects on other crops and markets. In this paper, we present findings of economic research on the impacts of GE crops at the farm level, factors that explain their adoption, impacts on prices, and effects on welfare of various segments in the economy. We rely on the findings of a new and thorough report by the National Research Council (NRC) (2010), a recent survey of agricultural biotechnology by Qaim (2009), and a new study by Sexton and Zilberman (2010).

The Impact of GE Crops at the Farm Level

A starting point for analyzing the impact of IR traits is the damage control function approach of Lichtenberg and Zilberman (1986). Actual crop output is given to be equal to potential output minus pest damage. Damage can be controlled by a variety of pest control techniques, including pesticides, cultural practices, and GE traits. By controlling pest damage, IR traits boost actual crop output and improve crop yields. The increase in yields due to the adoption of IR traits is expected to be small on farms that use the GE trait to substitute for chemical pest control applications. The effects will be larger where chemicals and other damage control approaches did not effectively control pest damage. Thus, developing countries, in which chemicals are not widely used, should benefit the most from IR technologies. Even in developed countries, however, where IR traits largely substitute for other effective control approaches, the costs associated with damage control, including pecuniary costs, environmental costs, and effort, decline.

The magnitude of yield gains associated with IR crop adoption also depends on the quality of the seed germplasm into which the IR trait is inserted. Since the Green Revolution, seed companies have bred high-yield seed varieties that are tailored to the specific agronomic conditions of heterogeneous farming regions. IR traits are not inserted into the best germplasm in all locations. If farmers must abandon a local seed cultivar in order to adopt an IR trait that is only available in a generic seed, then some yield loss may mitigate the yield gains associated with the damage control capabilities of the IR trait. This yield loss is called yield drag.

The NRC (2010) reported that adoption of IR crops throughout the United States resulted mostly in modest increases in yield and significant savings in pesticide costs. Yield drag was not evident. As Table 1 from Qaim (2009) showed, IR seeds that produce the naturally occurring toxin *Bacillus thuringiensis* (Bt), generally have much larger yield effects in developing countries than in developed countries. Bt cotton, adopted extensively in developing countries, has exhibited particularly large yield gains. In countries where the yield effects of Bt cotton adoption were modest, like China, Bt crop adoption has caused dramatic declines in pesticide use. Qaim (2009) also reports significant reductions in pesticide-related accidents and deaths associated with IR crop adoption.

Table1. Average Farm Level Agronomic and Economic Effects of Bt Crops

Country	**Insecticide reduction (%)**	**Increase in effective yield (%)**	**Increase in gross margin (US$/ha)**
		Bt cotton	
Argentina	47	33	23
Australia	48	0	66
China	65	24	470
India	41	37	135
Mexico	77	9	295
South Africa	33	22	91
USA	36	10	58
		Bt corn	
Argentina	0	9	20
Philippines	5	34	53
South Africa	10	11	42
Spain	63	6	70
USA	8	5	12

Source: Qaim, M., 2009.

While Qaim (2009) and NRC (2010) mostly presented results of studies that were done in the period between 2000 and 2006, the study by Sexton and Zilberman (2010) covers the period between 1996 and 2008. Based on a global survey of GE crop use, it shows that IR traits have had a much bigger yield effect than HT traits, especially in developing countries. The study suggests that in some countries soybean yield per acre might have been declining because of soybean expansion made possible by the elimination of late season weeds. But some of this expansion was not associated with increasing agricultural acreage per se. For example, much of the massive expansion in soybean acreage in Argentina was due to adding soybean as a second crop in a multiple cropping system. This adoption of double-cropping is possible with HT soybean because fallow periods between crops are reduced with use of less toxic chemicals and improved control of late season weeds.

While there is ample evidence that IR crops generally lead to higher yields, it is less clear that HR traits boost yields. Table 2 summarizes existing literature on HT yield effects. A number of studies find that there are no yield gains due to HT adoption, while others find that small yield gains accompany HT crop adoption. Fernandez-Cornejo, Klotz-Ingram, and Jans (2002), for instance, found on the basis of a national farm-level survey that HR soybean had a small advantage in yield over conventional soybean, likely because of better weed control.

Table 2. Summary of Primary Studies on the Effects of Herbicide Resistant (HR) Crops on Yields

Crop/Researchers/ Date of Publication	**Data Source**	**Effect on Yields**
Herbicide-tolerant soybeans		
Delannay et al., 1995	Experiments	Same
Roberts et al., 1998	Experiments	Increase
Arnold et al., 1998	Experiments	Increase
Marra et al., 1998	Survey	Increase
Fernandez-Cornejo et al., 2002[1]	Survey	Small increase
Duffy, 2001	Survey	Small decrease
Marra et al., 2004	Survey	Same
Bernard et al., 2004	Survey	Increase
Qaim and Traxler, 2005	Survey	Same
Herbicide-tolerant cotton		
Vencil, 1996	Experiments	Same
Keeling et al., 1996	Experiments	Same
Goldman et al., 1998	Experiments	Same
Culpepper and York, 1998	Experiments	Same
Fernandez-Cornejo et al., 2000[1]	Survey	Increase

Sources: Fernandez-Cornejo and Caswell, 2006; Bernard, Pesek, and Fan, 2004; and Qaim and Traxler, 2005.

In contrast, a national survey of soybean producers in 2002 found that there was no statistical difference in yield between conventional soybean and HR soybean (Marra, Piggott, and Carlson, 2004). Yet another study based on a mail survey of Delaware farmers in 2001 found that HR soybean had a three-bushel-per-acre yield advantage over conventional soybean (Bernard, Pesek, and Fan, 2004).

Whereas theory predicts IR traits will boost yields, the nature of HT traits suggests they will make damage control cheaper and easier, but not necessarily boost yields. HT traits permit the substitution of broad-spectrum glyphosates like Monsanto's Round-Up for more targeted, toxic and expensive chemicals that can kill specific weed species and leave crop plants intact. HT traits, therefore, do not constitute a new mechanism for damage control the way IR traits do. To make use of HT traits, farms must employ much of the same capital in weed control as is used with conventional seed. IR traits, on the other hand, require little capital and can substitute for chemical applications all together. To the extent HT traits reduce the costs of chemical applications, they may cause an increase in the use of chemical control, which can lead to yield gains as damage declines.

The NRC (2010) suggested that the adoption of IR and HT crops has a wide variety of benefits in addition to the immediate yield and cost-saving effects. Both traits can improve harvesting efficiency. IR crop reduces demand for inputs used in pestide applications, including machinery, fuel and water. The use of HT traits has led to increased adoption of no-tillage systems, which requires some modifications of equipment, but tends to significantly reduce fuel expenditures and effort, as well as reducing soil erosion. There are several studies that identify improved product quality and reduced damage in storage (NRC, 2010). Reduced yield risk associated with GE crops has affected farmers' need for insurance, and there is evidence that adopting farmers are receiving insurance premium discounts and gaining access to improved options for managing risks.

The benefits of GE crop adoption come at a price. Seed prices have increased with the introduction of GE technologies, and the share of seed prices in overall production costs has increased. Relative to 1994, seed prices have risen by 140% while the index of other input prices has increased by 80%. The highest price increase in the United States has been in cotton.

Many of the commercially available GE products have proven profitable to U.S. farmers, accounting for yield, cost, and other monetary effects. Furthermore, several studies document that nonpecuniary benefits to farmers were important causes for adoption of GE varieties (NRC, 2010). They include reduced management effort and work time, equipment savings, improved operator and worker safety, improved environmental safety, and total convenience (Marra and Piggott, 2006). These effects were not consistent and varied by location, but overall they are confirmed with evidence that GE crops save managerial time because of the associated simplicity and flexibility of pest control that they provide (Fernandez-Cornejo, Hendricks, and Mishra, 2005). As the NRC report recognized, standard measures of farm profits, such as net returns to management, give an incomplete picture of economic returns because they usually exclude the value of management time itself. However, recent studies show that adoption of management-saving technologies such as HR soybeans frees operators' time for off-farm employment, which leads to higher off-farm income (Fernandez-Cornejo, Hendricks, and Mishra, 2005; Gardner, Nehring, and Nelson, 2009).

Market Effects

Theory suggests that GE crops boost agricultural supply to the extent they boost farm yields. But by reducing damage and damage control costs, GE traits can also make it profitable to farm marginal land that cannot be profitably farmed with conventional seeds. Changes in supply affected commodity prices and, indirectly, the well-being of farmers and other sectors in the economy. There is a large body of literature that estimated the impact of GE varieties on commodity prices. Most of the studies reviewed by the NRC (2010) considered the early years of agricultural biotechnology adoption, when adoption rates were low. They found modest reductions in commodity prices of less than 2%. Over time, the effect of GE traits on crop prices may be higher—as much as 4%. The study by Sexton and Zilberman (2010), which considers global effects of GE traits, suggested price effects that are more substantial—greater than 10% in the case of cotton. Their analysis provides other evidence supporting the substantial effect of GE crops on commodity prices. The demand for soybean soared during the last 10 years with a growing demand for meat in Asian countries, especially China. The twofold expansion of soybean acreage around the world, largely due to HT soybean adoption, contributed to a large expansion of supply that was capable of meeting this growing demand with modest impact on prices. Similarly, cotton was a crop with the highest rate of overall adoption globally—90% adoption of Bt cotton in India—and the highest yield effect. Cotton was the only major crop that did not experience the agricultural commodity price inflation of 2007/2008, whereas staple crops for which GE traits were not available, like wheat and rice, experienced the highest price increases.

Several studies have investigated the distributional impact of the adoption of GE crops. These results appear in Table 3. Most of the studies suggested an overall gain from the adoption of these crops, but the distribution of benefits varies (NRC, 2010). The gain to farmers varies from 5% to 40%, depending on the price and yield effects, as well as the cost of the seed. The innovators captured between 10% and 70% of the benefits. Most studies found that they captured around 40%. The share of benefits to U.S. consumers varies from 6% to 60%, and the share of benefits captured by consumers in the rest of world also varies from 6% to more than 30%. The differences in outcomes reflect the heterogeneous effects of different types of seed innovations. The share of benefits accruing to consumers is likely to be greater for GE crops that benefit from larger yield gains characterized by very inelastic demand—that is, a small increase in supply reduces prices substantially. On the other hand, when the adoption of GE varieties mostly leads to substitution from chemical pesticides to GE varieties without significant changes in supply, much of the benefit will be captured by the farmers and the seed companies.

Most of the studies that analyzed the distributional effects of GE crops were undertaken early in the life of GE varieties. The result of the study by Sexton and Zilberman (2010) suggests that as the price effect of GE varieties increases because of increased adoption, the gain to consumers from their introduction becomes much more substantial.

Table 3. Benefits of the Adoption of Genetically Engineered Crops and Their Distribution

Study	Year	Total benefits ($ million)	Share of total benefits (%)			
			U.S. farmers	Innovators	U.S. consumers	Net ROW
Bt cotton						
Falck-Zepeda et al. (1999)	1996	134	43	47	6	
Falck-Zepeda et al. (2000a)	1996	240	59	26	9	6
Falck-Zepeda et al. (2000b)	1997	190	43	44	7	6
Falck-Zepeda et al. (1999)	1998	213	46	43	7	4
Frisvold et al. (2000)	1996–1998	131–164	5-6	46	33	18
US-EPA (2001)[a]	1996–1999	16–46	NA	NA	NA	NA
Price et al. (2003)	1997	210	29	35	14	22
Herbicide-resistant cotton						
Price et al. (2003)	1997	232	4	6	57	33
Herbicide-resistant soybean						
Falck-Zepeda et al. (2000b)	1997-LE[b]	1,100	77	10	4	9
	1997-HE[c]	437	29	18	17	28
Moschini et al. (2000)	1999	804	20	45	10	26
Price et al. (2003)	1997	310	20	68	5	6
Qaim and Traxler (2005)	1997	206	16[d]	49	35	NA[e]
Qaim and Traxler (2005)	2001	1230	13[d]	34	53	NA[e]

NA = not applicable; ROW = rest of the world (includes consumers and producers).
[a]Limited to U.S. farmers.
[b]LE = low elasticity; assumes a U.S. soybean supply elasticity of 0.22.
[c]HE = high elasticity; assumes a U.S. soybean supply elasticity of 0.92.
[d]Includes all soybean producers.
[e]Included in consumers and producers.

Source: NRC, 2010.

The Sexton and Zilberman study actually suggests that the price increases that would have occurred without the introduction of GE crops are of the same magnitude as the price effect associated with the diversion of corn, soybean, and other crops to produce biofuel between 2006 and 2008.

The NRC (2010) study found that producers of field crops gained overall from the introduction of GE varieties, but these gains are the net effect of higher yield, lower cost, and lower commodity prices. On the other hand, livestock producers in the United States and around the world have significantly benefited from the adoption of GM varieties. There is evidence that the nutritional characteristics of GE and conventional cultivars of soybean and corn are similar, and since feed consists of 50% of the cost of livestock production, livestock operators benefited from the reduction of commodity prices associated with the introduction of GE crops. They also benefited from increased feed safety with the reduction of mycotoxins in GE varieties.

The adoption of GE crops affected non-GE farmers as well. The introduction of Bt traits reduced the demand for and thus the price of insecticides that Bt replaced. The introduction of HT traits, on the other hand, increased the demand and thus the price of the herbicides that are used with these cultivars. There is some evidence that more effective control of pest damage associated with adoption of IR cultivars may reduce pest damage to neighboring crops that share the same pest population.

GE adoption also presents risk of gene transfer to neighboring non-GE crops and comingling of output, which imposes risk on nonadopting farmers. The regulatory constraints on use of GE traits may result in substantial economic impact when the traits are not used appropriately. One example is the case of Starlink, a GE corn hybrid that was approved for animal consumption but was mistakenly comingled with corn used for human consumption. This mistake resulted in significant penalties to the firm and fueled doubts about traceability and food safety. There is evidence that gene flow from GE cultivars resulted in mixing of some GE cultivars with non-GE cultivars (NRC, 2010).

To the extent that buyers establish strict standards on purity in purchasing non-GE crops, there can be substantial costs to non-adopters of gene flow from GE to non-GE varieties. Costs of preventing comingling and gene flow can also be substantial, and include the costs of extra screening and segregation of output throughout the supply chain, which can require redundant operations. Organic farmers may be especially vulnerable to such gene flow in cases where they operate under conditions of zero tolerance. More research is needed to understand some of the side effects of GE varieties on non-GE farmers. Improvements in technologies for tracing and separating commodities can enhance food safety and improve performance of supply chains, enabling more beneficial coexistence between GE and non-GE producers.

Future Prospects

GE crops are still in their infancy. Thus far, there is evidence that U.S. farmers who adopted these crops experienced lower costs of production and/or obtained higher yields. They also gained from substantial nonmonetary benefits. Overall, GE crops seem to improve farm profitability while also reducing commodity prices to the benefit of consumers. However, while rates of adoption of GE varieties in corn, soybean, and cotton have been dramatic in some countries, regulatory constraints have limited the spread of the technologies across the globe and thus diminished their benefits. The commodity price inflation of 2007/2008, the increased investment in biofuels, growing populations around the world, and the concern about greenhouse gas emissions suggest that an increase in agricultural productivity is essential. GE crops are one technology that can contribute to productivity gains.

The adoption of GE traits to control pests has been considerable in a small number of critical crops over the last 15 years. It has already made a major difference in increasing productivity, reducing food prices, and improving environmental quality. Yet, while the investment in new varieties grew steadily in the 1990s, it contracted significantly in 1999, the year the European Union instituted a de facto ban on GE technologies (Graff, Zilberman, and Bennett, 2009). In the last decade, we have seen a relative slowdown in the introduction of new GE varieties in spite of the dramatic expansion of land planted to the initial GE varieties. As the NRC (2010) suggested, there are hundreds of new traits in the pipeline, at various stages of development. These traits may contribute to improving food quality, especially feed quality, enhancing shelf life, and increasing drought tolerance.

The capacity to expand the utilization of GE technologies and fully take advantage of the potential of GE traits in agriculture requires continuous investment in research and an economic and regulatory environment that will foster development of new GE varieties. Further research is needed to understand the economics of the biotechnology industry and how it is affected by regulations and incentives. This may help to further improve the regulatory environment and generate conditions under which GE technologies can provide greater welfare improvements and promote environmental sustainability.

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