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Size and Distribution of Market Benefits From Adopting Biotech Crops

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Abstract

This study estimates the total benefit arising from the adoption of agricultural biotechnology in one year (1997) and its distribution among key stakeholders along the production and marketing chain. The analysis focuses on three biotech crops: herbicide-tolerant soybeans, insect-resistant (Bt) cotton, and herbicide-tolerant cotton. Adoption of these crops resulted in estimated market benefits of $212.5-$300.7 million for Bt cotton, $231.8 million for herbicide-tolerant cotton, and $307.5 million for herbicide-tolerant soybeans. These benefits accounted for small shares of crop production value, ranging from 2 percent to 5 percent. U.S. farmers captured a much larger share (about a third) of the benefits for Bt cotton than with herbicide-tolerant soybeans (20 percent) and herbicide-tolerant cotton (4 percent). Innovators' share ranged from 30 percent for Bt cotton to 68 percent for herbicide-tolerant soybeans. For herbicide-tolerant cotton, U.S. consumers and the rest of the world (including both producers and consumers) received the bulk of the estimated benefits in 1997. Estimated benefits and their distribution depend on the specification of the analytical framework, supply and demand elasticity assumptions, the inclusion of market and nonmarket benefits, crops considered, and year-specific factors (such as weather and pest infestation levels).

Keywords: Agricultural biotechnology, distribution of benefits, Bt cotton, herbicide-tolerant cotton, herbicide-tolerant soybeans.

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Summary

The adoption of biotech crops, particularly herbicide-tolerant soybeans and cotton, has been rapid since their commercial introduction in 1996. For example, herbicide-tolerant soybeans accounted for 81 percent of U.S. soybean acreage in 2003, leaping from 7 percent in 1996. Biotech crops can offer producers distinct advantages over conventional varieties, such as potentially higher yields and lower pest control costs.

But producers are not the only ones to gain from the adoption of agricultural biotechnology. Biotechnology developers and seed companies gain by charging technology fees and seed premiums to adopters who plant biotech varieties. Ultimately, U.S. and foreign consumers benefit from biotech crops through lower commodity prices, which result from increased supplies.

This study seeks to estimate the size and distribution of benefits from adopting the three most prevalent biotech crops—*Bacillus thuringiensis* (Bt) cotton, herbicide-tolerant cotton, and herbicide-tolerant soybeans—in 1997. The stakeholders considered in this study are U.S. farmers, U.S. consumers, biotechnology developers, germplasm suppliers, and producers and consumers in the rest of the world (ROW). We focus on specific and readily quantifiable market benefits accruing to stakeholders. As such, this analysis does not consider ease of pest management, a major factor in the rapid adoption of herbicide-tolerant soybeans. Similarly, nonmarket effects, including the environmental and health impacts of biotech crop adoption, are not considered in this study. Nor do we address the effects of adopting biotech crops on groups of consumers with different preferences toward biotech foods.

The estimated total benefit for each of the three biotech crops is measured in change to total welfare in both the seed input and commodity output markets. The theoretical framework accounts for monopoly profits in the input market. Because of intellectual property rights protection, the innovator prices the technology above marginal cost, allowing the firm to realize monopoly profit. The model also measures welfare changes for producers and consumers in a competitive output market, since some of the benefits generated by the innovation are passed on to them in the form of higher production efficiency and lower commodity prices.

In this study, the estimated total market benefit from adopting each of the biotech crops depends on the extent to which the commodity supply curve shifts outward after the introduction of the technology. In each case, the shift in supply reflects potential yield increases and savings in pest control costs. The estimated market benefit also depends on the interaction of the supply and demand curves before and after the introduction of the new technology. In this study, an empirical model is developed to calculate the pre- and post-innovation prices and quantities in an international market setting using information on adoption rates, crop yields, pest control costs, technology fees, and seed premiums. The framework takes into account the adoption of biotechnology outside of the United States, with assumptions regarding the efficiency of technology transfer to foreign countries.

For each of the three biotech crops in 1997, the estimated market benefits ranged from $213 million to $308 million. Our estimates of benefits from agricultural biotechnology are based on two data sources: data estimated from the 1997 Agricultural Resource Management Survey (ARMS) and a private database for Bt cotton. Both data sources isolate the effects of biotechnology on crop yields and pest control cost savings. Gains ranging from $212.5 million (ARMS) to $300.7 million

(private data source) were estimated from the planting of Bt cotton in 1997—3.6 percent to 5.1 percent of the value of upland cotton production. Herbicide-tolerant cotton improved total welfare by an estimated $231.8 million (3.9 percent of the value of upland cotton production), while the adoption of herbicide-tolerant soybeans yielded $307.5 million in total benefits (1.7 percent of the value of soybean production). These estimates are generally higher than those of previous studies in the case of Bt cotton, but lower for herbicide-tolerant soybeans.

The distribution of estimated benefits varied significantly across the three biotech crops. U.S. farmers received about a third of the estimated total benefit from adopting Bt cotton. (Previous studies estimated the share at around 50 percent.) In contrast, U.S. farmers captured just 20 percent of the estimated total benefit from adopting herbicide-tolerant soybeans—a share at the lower end of the benefit range reported in previous studies. With herbicide-tolerant cotton, a small U.S. farmers' share (4 percent) of the estimated total benefit was attributed to greater seed costs over conventional varieties and lower world prices (which offset the benefit of higher yields). Innovators captured 30 percent and 68 percent of the estimated total benefits from the adoption of Bt cotton and herbicide-tolerant soybeans. For herbicide-tolerant cotton, U.S. consumers and foreign producers and consumers received the bulk of the estimated benefits in 1997.

Estimates of biotech benefits are sensitive to a number of factors, including the analytical framework and supply elasticity assumptions. Sensitivity analysis indicates that changes in the U.S. and ROW supply elasticity assumptions have a more pronounced effect on the total benefit estimate than do changes in the U.S. and ROW demand elasticity assumptions. Supply elasticity assumptions affect the estimated benefits overall and those accruing to U.S. farmers more than for U.S. consumers. For example, doubling the supply elasticities reduces the estimated total benefit by about half in the case of herbicide-tolerant soybeans and causes U.S. soybean producers' share of the estimated total benefit to disappear.

Estimates of stakeholder benefits depend on the extent to which market benefits are captured in the analysis. Although not included in this study's benefit estimates, some important aspects of market benefits, such as the ease of pest management associated with herbicide-tolerant crops and the insurance value of insect-resistant crops, can affect the results. In addition, potential nonmarket benefits, including effects on the environment and human health, could influence the benefit estimates. As part of the environmental effects, biotechnology can potentially lead to lower pesticide use. Pesticide applications (measured in pounds of active ingredients) in 1997 were lower for Bt cotton in the Southeast, herbicide-tolerant cotton nationwide, and herbicide-tolerant soybeans in some major production regions. Other environmental and health benefits associated with the adoption of biotechnology, such as pesticide toxicity levels and the length of persistence in the environment, would factor into the total (nonmarket) benefits but are not part of this assessment.

Year-specific variables, including pest infestation levels, affect the size and distribution of benefits. For insect-resistant crops, such as Bt cotton, infestation levels of target pests can fluctuate over time. With low infestation, farmers are likely to derive fewer benefits from biotech crops. Weather conditions can also vary across growing seasons, which may affect potential yield enhancements associated with planting biotech crops. Hence, multiyear analyses are desirable to obtain more reliable estimates of the market benefits from agricultural biotechnology adoption.

Size and Distribution of Market Benefits From Adopting Biotech Crops

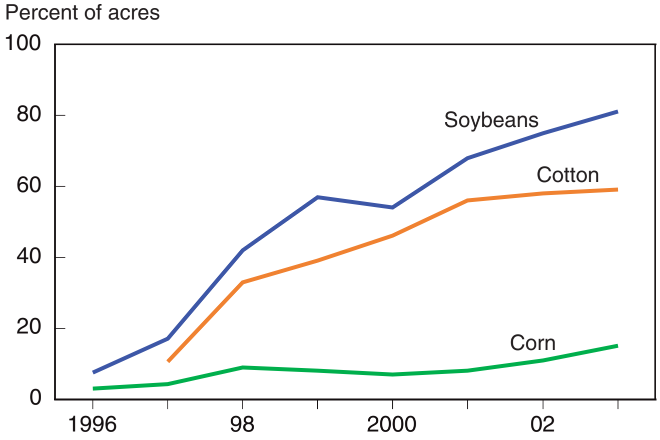
Gregory K. Price, William Lin, José B. Falck-Zepeda,
and Jorge Fernandez-Cornejo[1]

Introduction

The adoption of agricultural biotechnology has grown rapidly in the United States since its commercialization in 1996.[2] Herbicide-tolerant soybeans have been adopted particularly fast, from 7 percent of total soybean acreage in 1996 to 81 percent in 2003 (fig. 1; Smith and Heimlich; USDA, 2003). The adoption of herbicide-tolerant cotton has been nearly as fast, from about 10 percent of upland cotton acreage in 1997 to 59 percent in 2003.[3] In contrast, the adoption of herbicide-tolerant corn has expanded slowly, from 3 percent in 1996 to 15 percent in 2003. Compared with herbicide-tolerant soybeans and cotton, the adoption of insect-resistant (*Bacillus thuringiensis* or Bt) varieties has also grown slowly. During 1996-2003, Bt cotton (corn) adoption increased from 15 (2) percent in major producing States to 41 (29) percent nationwide (fig. 2; Smith and Heimlich; USDA, 2003).[4, 5]

Figure 1

Adoption of herbicide-tolerant soybeans, cotton, and corn in the United States, 1996-2003



Sources: Smith and Heimlich for 1996 and 1997 (using data from the Agricultural Resource Management Survey); USDA's March 2000 *Prospective Plantings* report for 1998 and 1999; and USDA's June 2001, 2002, and 2003 *Acreage* reports for 2000 through 2003. Adoption in 1998 and 1999 includes both biotech and conventional varieties with the herbicide-tolerant trait. Adoption rates for corn and cotton include both herbicide-tolerant only and stacked-gene varieties.

Overall, rapid growth in the adoption of biotech varieties reflects a desire by producers for potential crop yield increases, cost savings in pest control, and greater ease of management (including labor savings). Bt corn and cotton contain a gene that causes these crops to produce proteins that are toxic to certain pests but are harmless to other insects, humans, and animals. Herbicide-tolerant crops (soybeans, corn, and cotton) offer simple and flexible weed control programs and allow producers to use one herbicide without causing crop damage (Fernandez-Cornejo and McBride, 2002). As a result of these perceived benefits, U.S. plantings of biotech varieties increased from about 10 million acres in 1996 to 101 million acres in 2003 (Smith and Heimlich; USDA, 2003).

Consumers as a whole benefit from biotechnology in crop production because of greater supplies and lower market prices. This is especially true for consumers who are indifferent to biotech versus nonbiotech products. Consumers insistent on nonbiotech goods are

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[2] For purposes of this study, agricultural biotechnology refers to the use of recombinant DNA technology (DNA formed by combining segments of DNA from different organisms) to alter or move genetic material so that a plant (such as corn or soybeans) exhibits a desired trait as a result of gene insertion. Fernandez-Cornejo and McBride (2000) provide more detailed information about the basic concepts and definitions of agricultural biotechnology.

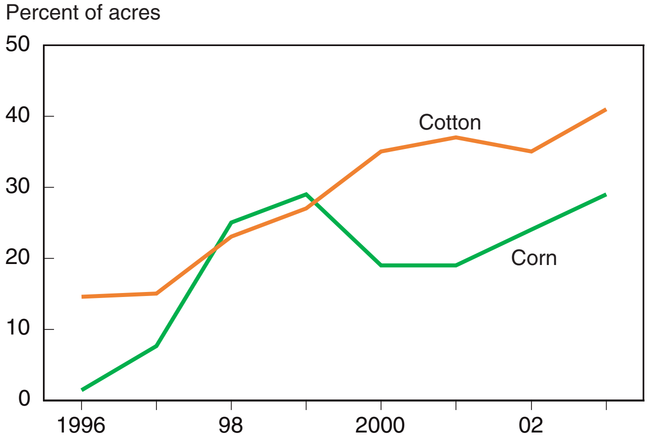
[3] The 2003 estimate for herbicide-tolerant cotton includes stacked-gene varieties, which possess both insect-resistant and herbicide-tolerant traits. Stacked-gene varieties accounted for 27 percent of U.S. upland cotton acreage in 2003.

[4] The 2003 estimates for Bt cotton and Bt corn include stacked-gene varieties, which accounted for 27 percent of total upland cotton acreage and 4 percent of total corn acreage.

[5] The decline in the adoption of Bt corn from 29 percent in major producing States in 1999 to 19 percent in 2000 may have been attributable, in part, to low infestation levels of European corn borers in 1998 and 1999 (USDA, 2001a).

Figure 2

Adoption of insect-resistant (Bt) corn and cotton in the United States, 1996-2003



Sources: Smith and Heimlich for 1996 and 1997 (using data from the Agricultural Resource Management Survey); USDA's March 2000 *Prospective Plantings* report for 1998 and 1999; and USDA's June 2001, 2002, and 2003 *Acreage* reports for 2000 through 2003. Adoption includes both Bt and stacked-gene varieties.

worse off since they have to pay premiums, which reflect the costs of product segregation. This study does not consider the welfare effects for consumers with divergent preferences for biotech foods.

Much debate has centered on how benefits from agricultural biotechnology are shared. Producers may benefit from higher net returns, but consumers may also benefit. Recent studies concur that U.S. farmers receive roughly one-half of the total estimated benefits (Falck-Zepeda et al., 1999, 2000a, 2000b; Paarlberg). However, some studies cite significantly different shares for U.S. farmers (Frisvold et al.; Falck-Zepeda et al., 2000a; Moschini et al.). These differences are attributable to varying methodological approaches, supply and demand elasticity assumptions, crops analyzed (e.g., herbicide-tolerant soybeans, Bt cotton), study periods investigated, and choice of data sources on farm-level impacts.

The purposes of this report are twofold: (1) to estimate the size of the total benefits that arise from the adoption of agricultural biotechnology; and (2) to measure the distribution of estimated benefits among key stakeholders—U.S. farmers, U.S. consumers, biotechnology developers, germplasm suppliers, and the producers and consumers in the rest of the world (ROW). We focus on market benefits from adopting herbicide-tolerant soybeans as well as Bt and herbicide-tolerant upland cotton in 1997, using data from the 1997 USDA Agricultural Resource Management Survey (ARMS)—the latest data available at the time of analysis—and a private data source for Bt cotton. The ARMS records U.S. producers' production practices, resource use, and financial condition, as well as the economic well-being of farm households. (Biotech corn is excluded from this study because 1996 ARMS data on Bt and herbicide-tolerant corn varieties may be inaccurate and unreliable due to low adoption that year—the first year of commercial availability; more recent data are unavailable.) This study uses ARMS data on potential crop yield gains and savings in pest control costs after isolating the effects of biotechnology on these farm-level effects.

Previous Related Studies

A number of studies have estimated the benefits associated with the adoption of biotech crops. These studies vary by types of benefits, stakeholders, crops, and years considered, as well as analytical frameworks employed. Studies that examine the distribution of estimated benefits among various stakeholders are limited to specific market benefits. Other studies focus on nonmarket impacts, such as changes in pesticide use and effects on the environment. Other differences include supply and demand elasticity assumptions, choice of data sources for farm-level effects (potential yield enhancements and/or savings in pest control costs), and the extent of farm-level impacts in the rest of the world relative to those in the United States. As a result of various approaches and assumptions, these studies yield different results.

Scope of the Analyses

Several studies have examined the distribution of estimated benefits for a range of stakeholders, including U.S. farmers, U.S. consumers, biotechnology developers, germplasm suppliers, and producers and consumers in the rest of the world. Falck-Zepeda et al. (1999; 2000a; 2000b) and Frisvold et al. estimated the distribution of benefits arising from the adoption of Bt cotton during 1996-98. Falck-Zepeda et al. (2000a) and Moschini et al. quantified the benefits from adopting herbicide-tolerant soybeans for those stakeholders in 1997 and 1999, respectively.

Other studies have estimated the benefits from biotech adoption for selected stakeholders. The U.S. Environmental Protection Agency (EPA) estimated the change in welfare realized by U.S. adopters of Bt corn and Bt cotton between 1996 and 1999. Their study uses a simple simulation model to estimate adoption rates and the distribution of growers' net benefits using a uniform probability distribution. Several studies have estimated Bt cotton growers' benefits from yield enhancements and/or savings in pest control costs (Stark; ReJesus et al.; Gibson et al.; Marra et al.; Mullins and Mills; Gianessi; Gianessi and Carpenter, 2000). While herbicide-tolerant soybeans did not offer significantly higher yields in the late 1990s, U.S. farmers benefited from lower total herbicide costs despite increased glyphosate use (Marra et al.; Gianessi et al.).

For Bt cotton, farm-level cost savings associated with reduced insecticide usage ranged from $28/acre to $47/acre for U.S. adopters in the late 1990s (Stark; Mullins and Mills). U.S. farmers were reported to have realized higher gross returns of up to $73 per acre due to higher yields (Stark). While herbicide-tolerant soybeans did not offer significantly higher yields, total herbicide costs decreased $11 per acre in 1996 despite increased glyphosate use (Marra et al.). Gianessi et al. estimated that herbicide-tolerant soybean adopters saved $20 per acre on weed control programs due to lower herbicide costs in 2001. Other studies report significantly smaller herbicide cost savings, ranging from $3 to $4.80 per acre (Rawlinson and Martin; Duffy and Vontalge; Lin et al., 2001).

Comprehensive studies of the distribution of benefits, such as those by Falck-Zepeda et al. (2000b) and Moschini et al., consider the market benefits realized by different stakeholders in the marketplace. These complex studies use data on the farm-level effects as well as other information (such as supply and demand elasticities and commodity trade flows) to determine changes in production, prices, commodity trade flows, and innovator profits.

While these analyses address some of the important market benefits for stakeholders, there are others that are not covered. Biotech crops offer other market benefits to producers, such as simplified and flexible weed management systems (Fernandez-Cornejo and McBride, 2002). In addition to fewer herbicide applications, the window of application for glyphosate in the case of herbicide-tolerant crops is relatively large, and post-emergence treatments do not reduce soybean yields or cause crop damage (Gianessi and Carpenter, 2000). Insect-resistant crops offer producers insurance against targeted pest infestation. Farmers who choose to grow biotech varieties anticipate that they will provide crop protection in the event that infestation occurs. This "insurance value" is an ex-ante market benefit for adopters since those producers must make the adoption decision before the true infestation levels are known.

These comprehensive studies do not consider nonmarket impacts, such as those on the environment and human health. The adoption of some biotech crops, such as Bt cotton, was shown to have reduced pesticide use because pest control is critical in cotton production. However, the reduction in pesticide use alone does not capture all of the potential environmental and health impacts of adopting biotech varieties.

Even if the adoption of some biotech crops may not lead to reductions in pesticide use, positive benefits to the environment may still arise. For example, glyphosate, in the case of herbicide-tolerant soybeans, is substituted for other synthetic herbicides that are typically used in the production of conventional varieties. Adopters of this technology can rely on one to two post-emergence herbicide applications instead of three to four to control a broad spectrum of weeds without causing crop injury (Gianessi and Carpenter, 2000). This should result in decreased fuel use for operation of farm machinery. In addition, compared with other synthetic herbicides, glyphosate is at least three times less toxic and persists in the environment half as long (Heimlich et al.; Ervin et al.; EPA). The use of glyphosate in conjunction with herbicide-tolerant soybeans has allowed farmers to adopt no-till and narrow-row planting practices, which aid in soil conservation (Carpenter and Gianessi, 1999a). Last, the adoption of herbicide-tolerant soybeans leads to lower water usage and imposes no restrictions on crop rotations (Ervin et al.; Gianessi and Carpenter, 2000).

Some studies assess the impact of biotech adoption in terms of changes in pesticide use (Gianessi and Carpenter, 1999 and 2000; Heimlich et al; Fernandez-Cornejo and McBride; Lin et al., 2001; and Gianessi et al.). For example, Gianessi et al. reported a decrease of 0.57 pound of active ingredients per acre for herbicide-tolerant soybean adopters in 2001. That value is much higher than the 0.02 pound-per-acre reduction shown by Lin et al. (2001) for adopters in 1997.

Other biotech crop studies explicitly analyze the impacts on wildlife. For example, EPA assessed the benefits of lower pesticide use through biotech adoption by determining the reduction in wildlife mortality and poisoning or death in humans. In the late 1990s, according to EPA, reduced use of conventional insecticides associated with Bt cotton led to fewer impairments to aquatic wildlife.

While most studies focus on the benefits of biotech crops, there are potential risks associated with the adoption of these varieties (Ervin et al.). These risks include the consequences of gene flow to wild species and the impacts on genetic diversity in the ecosystem. In addition, targeted pests may become resistant to specific pesticides. In some instances, biotechnology-derived traits could result in adverse effects on beneficial insects. However, these potential impacts and others are evaluated as part of the overall risk assessment for biotech crops prior to commercialization.

Analytical Framework

The works by Falck-Zepeda et al. (1999; 2000a; 2000b), Moschini et al., and Frisvold et al. aim to measure changes in surpluses for various stakeholders, including U.S. farmers, U.S. consumers, technology innovators, and producers and consumers in the rest of the world. In each study, welfare changes are calculated from commodity supply, demand, and prices under two different scenarios: (1) a base case where biotech adoption occurs, and (2) a counterfactual scenario where biotechnology is not available to producers.

The general approach used to measure the distribution of estimated benefits follows a spatial equilibrium modeling structure. The works by Falck-Zepeda et al. (1999; 2000a; 2000b) and Moschini et al. are based on a theoretical framework developed by Moschini and Lapan for assessing the welfare impacts of an innovation where the innovator behaves as a monopolist under the protection of intellectual property rights (IPR) in an input market. In addition to measuring changes in Marshallian surplus—the sum of producer and consumer welfare—in the commodity output market, which is characterized by a competitive structure, the Moschini and Lapan model calculates the monopoly profits captured by the innovator. In contrast, Frisvold et al. determine the benefits for adopters and nonadopters separately using a mathematical programming model, which accounts for the impacts of commodity price changes and government price support programs on the stakeholders' welfare.

Analytical frameworks employed in previous studies differ in their specifications concerning the form of commodity supply and demand as well as the nature of the supply shift attributed to biotechnology. Falck-Zepeda et al. (1999, 2000a, 2000b) specified linear supply and demand curves and assumed parallel shifts in supply (table 1). These two assumptions impose significant restrictions on the model structure. In such a framework, producer surplus cannot decline with an innovation that causes a parallel supply shift. In contrast, Frisvold et al. and Moschini et al. used nonlinear supply and demand

Table 1—Analytical framework specification in previous studies

Specification	Falck-Zepeda et al. (1999, 2000a, 2000b)	Frisvold et al.	Falck-Zepeda et al. (2000a)	Moschini et al.
	1996-98 *------------Bt cotton-----------*		*1997 herbicide-tolerant soybeans*	*1999 herbicide-tolerant soybeans*
Form of supply and demand curves	Linear	Nonlinear	Linear	Nonlinear
Supply shift	Parallel	Nonparallel	Parallel	Nonparallel

curves and assumed nonparallel supply shifts, which impose fewer restrictions on the model.

While there are a number of differences among these studies, they also exhibit some similarities. Falck-Zepeda et al. (1999, 2000a, 2000b) and Frisvold et al. estimated the changes in producer welfare in various U.S. production regions. Moreover, biotech adoption is determined endogenously through land allocation mechanisms for biotech and conventional varieties in the studies by Moschini et al. and Frisvold et al.

Falck-Zepeda et al. (1999, 2000a, 2000b) did not endogenize adoption decisions. Instead, actual adoption data were used as inputs in the estimation of the model. Unlike the other two studies, Frisvold et al. considered the effects of government program payments on the welfare of Bt and conventional cotton producers. Last, while other studies considered only the U.S. and ROW markets, Moschini et al. separated South America, a major U.S. competitor, from the ROW in their analysis of herbicide-tolerant soybeans. Moschini et al. also considered the entire soybean complex (including soybean oil and meal), while Falck-Zepeda et al. (2000a) limited their investigation to soybeans only.

Assumptions

Additional differences among the three prior studies on biotech crops lie in the supply and demand elasticity assumptions. Model results hinge upon these assumptions. U.S. supply elasticity assumptions are especially critical in affecting the size and distribution of estimated benefits because the technology's impacts are manifested through a shift in the supply curve.

The U.S. supply elasticity assumed in the models varies greatly in the case of Bt cotton, ranging from perfectly inelastic (within a small price interval) to 0.84 (table 2). The upper-bound U.S. supply elasticity in the Falck-Zepeda et al. (2000a) study on herbicide-tolerant soybeans is similar to that assumed by Moschini et al., but the lower value (0.22) is not. In general, a lower U.S. supply elasticity increases the size and share of the estimated benefits that accrue to producers.

Variation in the U.S. demand elasticity is not as large as for the U.S. supply elasticity, and variation in the net export demand elasticity is relatively small in the case of Bt cotton (table 2). Although there are differences in the ROW supply and demand elasticities, they are generally small (except for Moschini et al.).

Previous studies also make various assumptions regarding the efficiency of technology transfer to ROW producers (table 2). That is, to what extent (relative to the U.S.) are potential yield enhancements and savings in pest control cost realized by adopters in the rest of the world? A 100-percent efficiency means that the technology has the same farm-level effects in the rest of the world as in the United States. In the case of Bt cotton, Falck-Zepeda et al. (2000b) assumed a 50-percent efficiency in technology transfer to the rest of the world. This assumption was changed to 100 percent in a subsequent study (Falck-Zepeda et al., 2000a). (Frisvold et al. did not consider adoption of Bt cotton outside of the United States.) For herbicide-tolerant soybeans, a 100-percent efficiency was assumed in all previous studies.

Data

Estimates of the farm-level effects from biotech adoption have come from various sources. In the case of Bt cotton, both Falck-Zepeda et al. (2000b) and Frisvold et al. relied on average values obtained from surveys of county agents, State extension specialists, private

Table 2—Parameter assumptions in previous studies: Supply and demand elasticities and efficiency of technology transfer

Parameter	Falck-Zepeda et al. (1999, 2000a, 2000b)	Frisvold et al.	Falck-Zepeda et al. (2000a)	Moschini et al.
	1996-98 ------------*Bt cotton*-----------		*1997 herbicide-tolerant soybeans*	*1999 herbicide-tolerant soybeans*
U.S. supply elasticity	0.84	0[1]	0.22 and 0.92	0.8
U.S. demand elasticity	-0.101	-0.3	-0.42	-0.4
Net export demand elasticity	-1.62	-2.0	-0.614	n.a.
ROW supply elasticity	0.15	0.05	0.3	0.6
ROW demand elasticity	-0.13	-0.09 to -0.14	-0.07	-0.4
South America supply elasticity	n.a.	n.a.	n.a.	1.0
South America demand elasticity	n.a.	n.a.	n.a.	-0.4
	----------------------------*Percent*---------------------------------			
Efficiency of technology transfer to ROW	50-100	0	100	100

n.a.= Not applicable. ROW = Rest of the world.

[1] By the nature of a step supply function, the U.S. supply elasticity is perfectly inelastic for small price changes.

consultants, and research entomologists (Williams). Falck-Zepeda et al. (1999 and 2000a) also used the Enhanced Market Data II, a private-sector source applicable to the Southeast region (Plexus Marketing Group, Inc., and Timber Mill Research, Inc.). Unlike other data, this source isolates the impacts of biotechnology on cotton yields and insect control costs by comparing Bt and non-Bt fields that are similar with respect to weather, agronomic conditions, and production practices.

For herbicide-tolerant soybeans, Moschini et al. used information from an Iowa State budget on the costs of production. In contrast, Falck-Zepeda et al. (2000a) used the average difference between yields and pest control costs as reported by adopters and nonadopters in the ARMS.

Significant differences across data sources have contributed to a wide range of estimates for stakeholders' benefits. For example, Falck-Zepeda et al. (2000a) assumed a 13-percent yield increase for herbicide-tolerant soybean adopters in the Corn Belt. In contrast, adopters in the study by Moschini et al. were assumed not to have realized any yield advantage. This difference caused U.S. farmers to capture a larger share of the estimated total benefits in the study by Falck-Zepeda et al. (table 3).

Other data assumptions have influenced the distribution of estimated benefits. Falck-Zepeda et al. (1999, 2000a, 2000b) assumed that the proportion of U.S. cotton production exported to the rest of the world matches the proportion of imports relative to ROW cotton production. This assumption implicitly postulates that the consumption-to-production ratio in the United States is identical to that in the rest of the world. Furthermore, the proportion of regional production exported to the ROW was assumed to be the same as at the national level (40 percent). In determining the benefits for U.S. and rest of the world stakeholders, regional distribution data may be used to more accurately account for domestic use and exports (Glade et al.).

Results of Previous Studies

In general, past studies have found that the bulk of estimated benefits accrue to U.S. producers and technology innovators (biotechnology developers and germplasm suppliers). However, reported benefits to U.S. farmers and the biotech/seed firms vary greatly (table 3). In the case of Bt cotton, U.S. producers earned 5-59 percent of the estimated total benefit and innovators received 26-47 percent. For herbicide-tolerant soybeans, U.S. farmers realized 20-77 percent of the estimated total benefit and innovators captured 10-45 percent.

Table 3—Benefits and their distribution from previous related studies

Study	Year	Total benefits	Share of the total benefits			
			U.S. farmers	Innovators	U.S. consumers	Net ROW
		$ million	*Percent*			
Bt cotton						
Falck-Zepeda et al.(1999)	1996	134	43	47	6	4
Falck-Zepeda et al. (2000b)	1996	240	59	26	9	6
Falck-Zepeda et al. (2000a)	1997	190	43	44	7	6
Falck-Zepeda et al. (1999)	1998	213	46	43	7	4
Frisvold et al.	1996-98	131-164	5-6	46	33	18
EPA[1]	1996-99	16.2-45.9	n.a.	n.a.	n.a.	n.a.
Herbicide-tolerant soybeans						
Falck-Zepeda et al. (2000a)	1997-Low elasticity[2]	1,100	77	10	4	9
	1997-High elasticity[3]	437	29	18	17	28
Moschini et al.	1999	804	20	45	10	26

n.a. = Not applicable. ROW = Rest of the world.

[1] Limited to U.S. farmers' benefits.

[2] Assumes a low U.S. soybean supply elasticity of 0.22.

[3] Assumes a high U.S. soybean supply elasticity of 0.92.

Key parameters affecting these shares include specification of the analytical framework, supply and demand elasticity assumptions, farm-level effects, and year-specific variables (table 3). In terms of farm-level effects, the lack of yield advantage for herbicide-tolerant soybeans assumed by Moschini et al. contributed to a 20-percent share of the estimated benefits for U.S. farmers. This share increased to 29 percent (under the higher supply elasticity assumption) when a 13-percent increase in adopters' yields was assumed for the Corn Belt (Falck-Zepeda et al., 2000a).

Producers directly benefit from the adoption of biotech crops through potentially higher yields and savings in pest control costs. Consumers may also benefit through lower commodity prices. Most studies found that U.S. consumers received no more than 10 percent of the estimated total benefits, though Frisvold et al. reported 33 percent.

On a net basis, the rest of the world generally obtained a small portion of estimated benefits from biotech adoption in the United States. However, some studies report benefit shares of 18-28 percent for the rest of the world when both producer and consumer benefits are considered. ROW consumers gain from the worldwide adoption of biotech crops because of lower commodity prices, and their surplus gains always exceed the losses of ROW producers in previous studies. Producers in other countries realize welfare losses primarily for two reasons: (1) widespread production of conventional varieties in the rest of the world without the yield advantages and/or cost savings associated with biotech crops, and (2) exposure to lower prices caused by the rapid adoption of biotech crops in the United States.

Theoretical Framework

The size and distribution of benefits from the adoption of biotech crops have been subjects of public debate since the crops' commercialization in the mid-1990s. While many studies have investigated these issues, their results vary. The purpose of this study is to explain how variability in specific factors can lead to differences in the reported benefits.

To measure the economic benefits resulting from the adoption of biotech crops, one must consider potential yield enhancements, savings in pest control costs, and efficiency of technology transfer to ROW producers—all in the context of supply and demand in the U.S. and global market. The farm-level effects associated with biotechnology shift the commodity supply curve to the right (i.e., more supply at a given price). With a given demand, this shift leads to a reduction in the price of the commodity. The theoretical framework employed in this study measures the change in Marshallian surplus in the output market resulting from the adoption of biotech crops. The model also captures monopoly profits accruing to technology innovators in the seed input market.

Moschini and Lapan Model

Moschini and Lapan provided a framework for modeling welfare changes where a new technology results in production cost savings and the innovator enjoys intellectual property rights (IPR) protection. This model serves as the theoretical foundation for this study. In the case of biotech crops in the United States, IPR protection is typically enforced through licensing agreements between the innovators and producers.

In the Moschini and Lapan model, an input firm develops a new technology. Through patent protection or trade secrecy, the innovator acquires a temporary monopoly, thus allowing the firm to set the input's price above its marginal cost of production. The introduction of this new input does not affect the purely competitive nature of the output market. An important contribution of the Moschini and Lapan model is that—unlike previous studies of public agricultural innovations, such as those cited by Alston et al.—its welfare measurement includes monopoly profits occurring in the input market that are induced by IPR protection.

The new technology requires fewer inputs than the old technology to produce the same level of output. In other words, the innovation increases production efficiency. To characterize this gain, Moschini and Lapan used a scaling factor to express the more efficient input as a fraction of the pre-innovation input. The increase in efficiency can also be translated into a reduction in input price.

Moschini and Lapan developed output supply and input demand functions under the hypothesis that, given input and output prices, producers maximize profit. Producers adopt the new technology if the per-unit cost reduction is greater than the price differential between the two technologies.

The price of the new input depends, in part, on the demand for the commodity in the output market. Moschini and Lapan assumed that the output market is competitive. The interaction of output supply (S_0) and demand (D) results in the equilibrium price (P_0) and quantity (Q_0) when only the old technology is available (fig. 3). Since the new technology is more efficient and yields more output with the same amount of inputs, the supply curve shifts to the right (denoted by S_1). The equilibrium price and quantity with the new technology are P_1 and Q_1.

It is assumed that the old input is supplied in the input market at marginal cost, MC_0 (fig. 4). Prior to the

Figure 3

Effect of introducing a more efficient technology in the output market

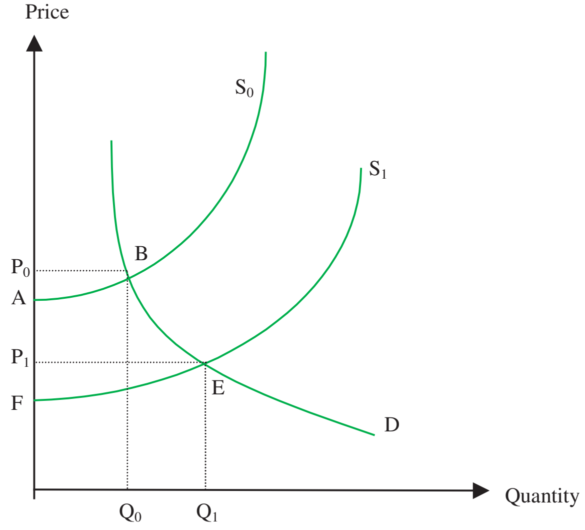
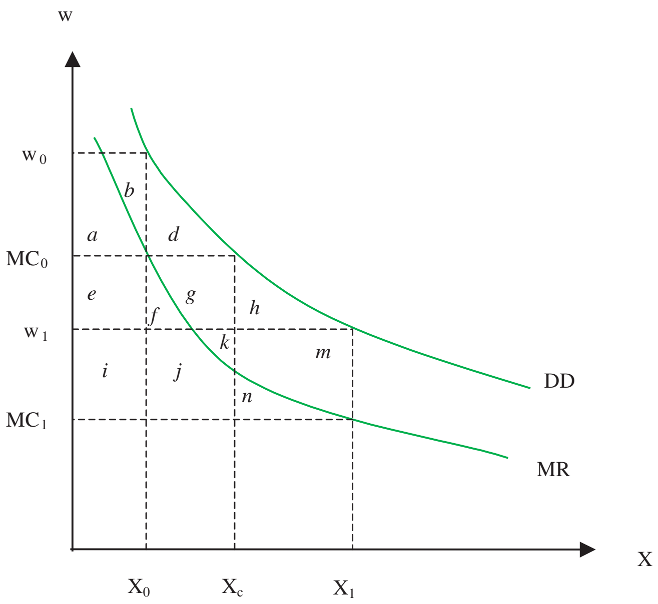


Figure 4

Drastic innovation in the input market



introduction of the new technology, the input is priced at MC_0 if the input market is competitive. In that case, the equilibrium demand is x_c. Because the firm faces a downward-sloping derived demand curve (DD), it is able to price the new input above its marginal cost. If the firm acts as a monopolist with the old technology, the optimal usage (x_o) is determined at the intersection of the marginal revenue (MR) curve and MC_0, with the equilibrium price being w_0.

With the introduction of the new technology, the marginal cost falls to MC_1 due to the efficiency gain. Because the firm is protected through IPR, the monopolist maximizes profit by producing the input quantity x_1 at the equilibrium price w_1. This theoretical framework postulates that the competitive market structure for the traditional input does not affect the price charged by the monopolist for the new input.

Because of the firm's price-setting ability, the monopolist retains a portion of the surplus, with the remainder being passed on to producers and consumers in the output market (Huffman). Total welfare must be measured in both the output and input markets in order to account for surpluses accrued to producers and consumers as well as the monopoly profits induced by IPR. Thus, the total change in social welfare due to the introduction of the innovation comprises two components: (1) the change in Marshallian surplus in the output market, and (2) the monopolist's profit in the input market. The equivalent change in Marshallian surplus in the input market is represented by the area (e+f+g+h), which is the difference between the Mashallian surpluses in the competitive, pre-innovation market—area (a+b+d)—and the monopolistic, post-innovation market structure—area (a+b+d+e+f+g+h). Producers' welfare increases in the input market due to the higher efficiency of the new input. Consumers also benefit from the new technology through increased output and lower commodity prices. Thus, the change in Marshallian surplus is shared among producers and consumers. The change in Marshallian surplus in the input market is identical to that in the output market, which is denoted by area ABEF in figure 3. The monopolist's profit is denoted by the area (i+j+k+m+n) in figure 4.

Several conclusions can be drawn from Moschini and Lapan's conceptual model. First, to measure total welfare, one must estimate traditional Marshallian surplus and then add the value of the change in monopoly profits induced by the innovation. Monopoly profits help the innovator to recover research and development expenditures, which can be costly in the case of biotech crops. Without these profits, few incentives to develop these technologies would exist. Second, Marshallian surplus can also be estimated from the derived demand function for the input or from the supply function for the output. Third, for empirical applications, one must determine whether market power existed prior to the innovation in order to determine if the measurement procedure described above is appropriate.

This theoretical framework suggests that firms increase research and development expenditures if IPRs are well-defined and firms are assured a minimum market size. On the other hand, firms that attempt to extract too much surplus by overpricing inputs may attract competitors or limit their market shares by discouraging adoption of the new technologies. The adoption of new technologies depends on whether the expected additional revenues from greater per-unit output and/or lower input costs outweigh the higher cost of the innovation, including technology fees.

Empirical Model

Alston et al. developed a methodology for calculating Marshallian surplus. Their framework is well established in the economics literature and allows research-induced benefits generated in an output market to be partitioned between producers and consumers. Falck-Zepeda et al. (2000b) modified the approach of Alston et al. to account for monopoly profits induced by IPR protection in the input market, as suggested by Moschini and Lapan. This is the empirical model used here.

The modified framework characterizes a large, open U.S. economy, as well as technological transfer to the rest of the world. This model structure allows for trade between the United States and the rest of the world and assumes that the United States can significantly affect world prices through its exports. The framework postulates that commodity supply and demand functions can be modeled using linear equations. Details of the model structure are in Appendix A.

Biotech crops potentially offer yield increases and savings in pest control costs, which may improve profitability. Per-acre yield enhancements are converted to a per-ton cost savings by dividing the yield changes by the U.S. supply elasticity (Alston et al.). Changes in per-acre pest control costs are converted to a per-ton basis by dividing them by one plus the per-acre yield change caused by biotechnology. These farm-level benefits typically come at a higher cost through technology fees charged by biotechnology developers and seed premiums levied by seed companies. The net change in input costs associated with biotech adoption is the sum of the equivalent per-ton cost savings from yield enhancements and pest control minus the technology fees and seed premiums. This change leads to a shift in the supply curve and is represented by the vertical distance between the pre-innovation and post-innovation supply curves.

If biotech crops are not available to ROW producers, only the U.S. supply curve moves. On the other hand, if biotech crops are available worldwide, then both the U.S. and ROW supply curves shift to the right. The extent to which the ROW supply curve shifts to the right depends on the efficiency of technology transfer to ROW producers. If they realize the same yield enhancements, savings in pest control costs, and innovation fees as U.S. farmers, the vertical supply shift in the two regions will be the same. In contrast, if ROW producers realize only half of the net efficiency gains as U.S. farmers, the vertical supply shift will be half as large as in the United States.

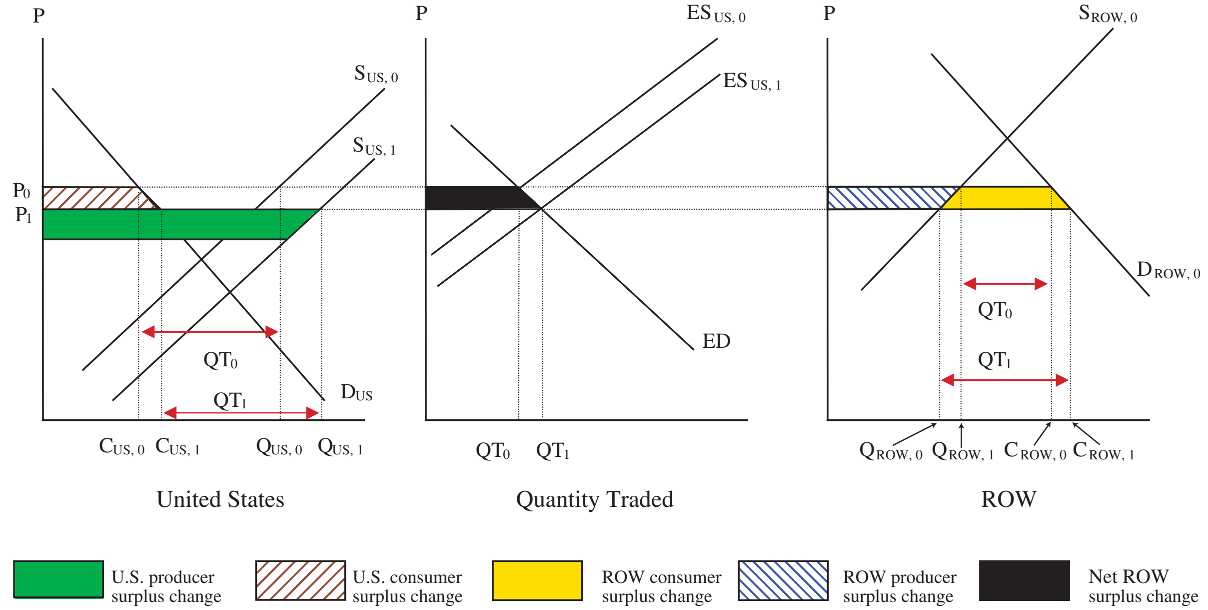
Once a new technology is introduced and adopted, only the world price that results from the supply shift can be observed. It is not possible to observe the counterfactual price—the price that would have existed, assuming the same supply and demand conditions, if biotechnology had not been introduced. Estimated changes in stakeholders' welfare are made by comparing their surpluses that arise with and without the innovation. The base case reflects the observed market supply and demand as well as the resulting equilibrium price with the introduction of the innovation. The supply shift is calculated based on the net cost savings due to yield enhancements and lower pest control costs for adopters after accounting for technology fees and seed premiums paid to the innovators. The counterfactual world price, which reflects the equilibrium world price without the innovation, is the sum of the observed market price and the vertical supply shift.

The equilibrium world price occurs at the intersection of the excess supply and excess demand curves (fig. 5). (For simplicity, figure 5 assumes no technological transfer to the rest of the world. While the empirical results would differ without this assumption, the approach for measuring surplus changes for producers and consumers remains the same.) The pre-innovation excess supply curve is denoted by $ES_{US,\,0}$, while the post-innovation supply curve is $ES_{US,\,1}$. The excess supply curve maps the horizontal difference between the U.S. supply ($S_{US,\,0}$ in the case of $ES_{US,\,0}$ and $S_{US,\,1}$ for $ES_{US,\,1}$) and demand (D_{US}) curves at every price above the domestic equilibrium price. Similarly, the excess demand curve (ED) is a locus of points indicating the horizontal difference between the ROW demand ($D_{ROW,\,0}$) and supply ($S_{ROW,\,0}$) curves at every price below the ROW equilibrium price. Before the introduction of the technology, the equilibrium world price is P_0, but falls to P_1 because the introduction of the innovation causes a rightward shift in supply. The quantity traded in the post-innovation market (QT_1) is determined at the intersection of the excess supply ($ES_{US,1}$) and excess demand (ED) and equals the volume exported by the United States and imported by the rest of the world. The quantity traded in the pre-innovation market is computed in the same manner.

U.S. consumer welfare prior to the introduction of biotechnology is bounded by the area below the demand curve (D_{US}) and above the counterfactual world price, P_0. The innovation increases U.S. consumer surplus due to the decline in the world price. The new U.S. consumer surplus becomes a larger triangular area, including the pre-innovation U.S. consumer surplus plus the hashed area between P_0 and P_1. Thus, the change in U.S. consumer surplus is denoted by the hashed area. The formula for computing the change in U.S. consumer surplus is included in Appendix A.

Figure 5

Marshallian surplus distribution



U.S. producer surplus prior to the introduction of biotechnology is represented by the area below P_0 and above the pre-innovation supply curve, $S_{US,\,0}$. After the innovation, U.S. producer surplus becomes the area below P_1 and above the post-innovation supply curve, $S_{US,\,1}$. The change in U.S. producer welfare is the area between the two supply curves below P_1 minus the area between P_0 and P_1 above the pre-innovation supply curve. With the assumptions of linear supply and demand curves as well a parallel shift in supply, this change is identical to the green area in the U.S. panel (fig. 5; Alston et al.).

Monopoly profits accruing to the innovators depend, in part, on the technology fees and seed premiums charged to farmers in the United States and ROW. The firms' profits also hinge on the rate at which biotech crops are adopted. While it is possible to estimate the gross revenues realized by the innovators, it is difficult to measure the monopoly profits obtained from biotechnology. First, the agreements between the biotechnology developers and germplasm suppliers are typically confidential, so it is nearly impossible to account for the revenue-sharing schemes agreed upon by the companies. Second, revenue estimates do not consider certain variable costs, such as those associated with administrative, marketing, and IPR enforcement activities. Third, the characterization of research and development costs as either variable or sunk costs is problematic in the calculation of monopoly profits. In this study, monopoly profits are estimated using information on technology fees and seed premiums, acreage planted to biotech crops, and company reports concerning their licensing agreements (Falck-Zepeda et al., 2000b). This analysis excludes the above variable expenses, and hence, might overstate the innovators' profits.

In this study, an empirical model is applied to the adoption of Bt cotton as well as herbicide-tolerant soybeans and cotton in 1997. That year was selected due to the availability of ARMS data on the farm-level effects of biotech and conventional varieties. The United States had a significant presence in the global cotton and soybeans markets—21 percent and 46 percent of world production and 28 percent and 59 percent of world trade in 1997 (USDA, 2000c and 2001c). Technology transfer to ROW producers was incorporated in the framework because two of the three biotech crops were commercially available outside of the United States—Mexico and Australia in the case of Bt cotton and Argentina and Canada for herbicide-tolerant soybeans (James).

To determine the size and distribution of benefits realized by U.S. farmers, U.S. consumers, technology innovators, and ROW consumers and producers, the following steps were applied:

(1) Estimate the technology-induced supply shift for each commodity-producing region using data on adoption rates, crop yields, and savings in pest control costs net of technology fees and seed premiums;

(2) Calculate the impacts of the new technologies on world and regional prices; and

(3) Estimate the changes in the Marshallian surpluses in the United States and ROW and partition them between producers and consumers.

Profits for biotechnology developers and seed companies are determined outside of the above framework. Data on adoption rates, technology fees, and seed premiums are key to determining innovators' profits. These variables are fixed in the base case.

Farm-Level Effects on Crop Yields and Pest Control Costs

Benefits to producers from adopting biotech crops can be represented by a shift in supply, reflecting potential increases in crop yields and/or savings in pest control costs. U.S. and ROW consumers indirectly benefit from biotech adoption because increased crop supplies lower commodity prices. Because the technology-induced supply shift affects the surpluses of both producers and consumers, accurate information is needed about biotechnology's farm-level impacts.

This section details the impacts of biotechnology on crop yields and pest control costs. These estimated benefits are only a subset of the entire economic impact of biotechnology. Changes in pesticide use attributed to the adoption of biotechnology do not capture all the potential environmental and health impacts. Other benefits not covered include the ease of pest management associated with herbicide-tolerant crops and the insurance value against the potential infestation of targeted pests for Bt cotton (Fernandez-Cornejo and McBride, 2002).

Data Sources

Potential increases in crop yields and savings in pest control costs associated with the adoption of biotechnology are difficult to quantify. This section discusses two data sources that were used to measure the farm-level effects employed in this study.

Producer surveys are a primary data source for measuring differences in crop yields and pest control costs between adopters and nonadopters of a given biotech crop (e.g., Falck-Zepeda et al., 2000b). Survey data reflect actual producer costs associated with the use of each crop production technology. Moreover, survey data can be used to show frequency distributions of crop yields and pest control costs for adopters and nonadopters separately, as well as associated statistics, such as mean values and standard deviations.

The Agricultural Resource Management Survey (ARMS), a nationwide USDA producer survey, has been used by some researchers to quantify the farm-level impacts of biotechnology (Falck-Zepeda et al., 2000a). Farm financial and chemical use data are reported for all crops in the ARMS survey each year, while detailed enterprise production practices and cost data are collected for several commodities (including soybeans and cotton) on a rotating basis every 4 to 7 years (McBride).[6]

According to McBride, four characteristics of the ARMS data make it useful for assessing the farm-level impacts of biotech adoption. First, the ARMS has broad coverage, including all of the major producing States for a given commodity—generally more than 90 percent of the crop acreage. Second, ARMS uses a stratified random sample, where each farm represents a known number of similar farms in the population, based on sampling probabilities. Each farm is weighted by the number of farms it represents so that the ARMS sample can be expanded to reflect the targeted population. Third, ARMS enterprise cost-of-production data contain sufficient detail about specific inputs to isolate seed and pest control costs associated with commodity production. Finally, since enterprise cost-of-production data can be obtained for each responding farm, a distribution of costs can be developed.

An alternative to using producer survey data is to rely on State enterprise cost-of-production budgets estimated by State extension programs at land-grant universities. These budgets for biotech and conventional crop varieties are relatively inexpensive to obtain and can be easily modified for use in research applications (e.g., Duffy and Vontalge). One advantage of using these data is that factors other than the choice of crop variety can be controlled in order to isolate the cost difference between the two technologies (McBride). However, these data may not be representative of the entire farm population because input and output levels often reflect above-average management. In addition, State budgets are location specific, mainly for a State or a portion of a State, thus making it difficult to represent a broad population and/or geographic area. More important, enterprise budgets are typically not comparable across States because of inconsistencies in design and the inclusion of biotech crops. In fact, many States do not differentiate their enterprise budgets between biotech and conventional varieties.

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[6] The 1997 ARMS data are used in this study because these are the latest available information on cotton and soybeans.

In this study, farm-level impacts resulting from biotech adoption are estimated from ARMS data—hereafter called “estimated ARMS effects”—using an econometric procedure that excludes the effects of other factors (Fernandez-Cornejo et al.; Fernandez-Cornejo and McBride). The econometric model accounts for the fact that farmers’ adoption of biotechnology and pesticide use decisions may be simultaneous. In addition, the model corrects for self-selectivity to prevent biased results. Self-selection arises because farmers are not assigned randomly to one of the two groups (i.e., either adopters or nonadopters). Instead, they make the adoption choices themselves. Therefore, adopters and nonadopters may be systematically different, and these differences may manifest themselves in farm performance, which could confound the effect of biotech adoption.

Results of the econometric model are expressed in elasticity form. In terms of the impact on crop yields, the adoption of herbicide-tolerant soybeans has a small but positive and significant effect. U.S. herbicide-tolerant soybean yields in 1997 were estimated to have increased by less than 1 percent for a 10-percent increase in adoption (Fernandez-Cornejo and McBride). This yield effect is generally consistent with other studies (Gianessi and Carpenter, 2000; Carpenter and Gianessi, 1999b, 2000; Moschini et al.; Duffy and Vontalge). For Bt cotton in the Southeast and herbicide-tolerant cotton nationwide, yields in 1997 were estimated to have increased by 1 to 5 percent for a 10-percent increase in adoption (Fernandez-Cornejo and McBride).

The impact of biotech adoption on pesticide use, based on this econometric model, varies by commodity and across active ingredients. An increase in the adoption of herbicide-tolerant soybeans was estimated to have led to a statistically significant reduction in the use of herbicides other than acetamides and glyphosate, which fell 1.4 percent for a 10-percent increase in adoption in 1997 (Fernandez-Cornejo et al.). In contrast, the adoption caused a significant increase in glyphosate use, which rose 4.3 percent for a 10-percent increase in adoption. The change in acetamides was not statistically significant.

For each herbicide active ingredient, the rate of application and the share of area applied vary by region. Thus, the change in herbicide use by category (e.g., acetamides and other herbicides) differed across production regions. The net effect of an increase in biotech adoption on herbicide use depended on the extent to which the decrease in the use of other herbicides offset the increase in glyphosate use.

An increase in the adoption rate of Bt cotton did not lead to a significant change in the use of organophosphate and pyrethroid insecticides (Fernandez-Cornejo et al.). However, a 10-percent increase in adoption led to a 2.1-percent decrease in the use of other insecticides in the Southeast, which was statistically significant. Thus, the net effect of an increase in the adoption of Bt cotton in that region was a decrease in total insecticide use. The change in herbicide use nationwide associated with the adoption of herbicide-tolerant cotton was not statistically significant.

Other data sources for quantifying the farm-level impacts of biotech adoption are databases maintained by private firms. For example, in their study of 1997 Bt cotton, Falck-Zepeda et al. (2000a) used the comprehensive Enhanced Market Data II, or EMD (Plexus Marketing Group, Inc., and Timber Mill Research, Inc.). These data were derived from surveys in which cotton consultants provided agronomic and pest management information on matched pairs of Bt and non-Bt cotton fields in the same locations. To ensure similarity, the matched pairs of fields were carefully selected so that they represented equivalent agronomic practices and productivity. The EMD covers fields in Alabama, Arkansas, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, and east Texas. Like the estimated ARMS effect in the Southern Seaboard, the EMD isolates the impacts of biotechnology on crop yields and pest control costs.

Estimated Impacts on Crop Yields

To truly calculate farm-level effects of biotech crops, one must discern the difference in crop yields (between adopters and nonadopters) that is attributable to the technology. This section discusses the impact on crop yields across the two data sources: (1) the estimated ARMS effects based on the econometric model for all three biotech crop varieties, and (2) the EMD database, which is applicable only to Bt cotton produced in the Southeast. The impact of adopting Bt cotton on crop yields, based on 1 year of data (1997), appears to vary significantly across the two data sources and production regions. In the Southern Seaboard, yields for Bt cotton adopters are estimated to have been higher than for nonadopters in both data sources, as shown in table 4 (see figure 6 for ERS crop

Table 4—Impact of adopting Bt cotton on crop yields by region and by data source, 1997

Production region	Data source Estimated ARMS effect	 EMD
	Percent	
Southern Seaboard	+21.0	+11.3
Fruitful Rim	n.a.	n.a.
Mississippi Portal	n.a.	+ 3.7
Eastern Uplands	n.a.	n.a.

n.a. = Not applicable. EMD = Enhanced Market Data II.

Sources: Estimated ARMS effects adapted from Fernandez-Cornejo et al. EMD obtained from Plexus Marketing Group, Inc., and Timber Mill Research, Inc.

production regions).[2] For example, according to the estimated ARMS effects, Bt cotton adopters' yields in the Southern Seaboard averaged about 847 pounds per acre, compared with 700 pounds for nonadopters, a 21-percent advantage.

The estimated ARMS effect indicates a 17-percent increase in yields for herbicide-tolerant cotton adopters nationwide. In some regions, herbicide-tolerant cotton yields may have been lower than for conventional varieties. In particular, farmers in the Mississippi Portal encountered serious and unexpected problems with their herbicide-tolerant cotton during the 1997 growing season (Virginia Cooperative Extension). Some growers found deformed bolls and bolls that dropped off the plants. About 20 percent of the region's herbicide-tolerant cotton was affected. However, the problems may have been caused by factors other than the herbicide-tolerant technology itself, such as soil type and weather conditions.

For herbicide-tolerant soybeans, the estimated ARMS effect indicates only 3-percent higher yields for adopters nationwide, which is consistent with other studies' findings that the adoption of herbicide-tolerant soybeans has little or no overall impact on soybean yields (Gianessi and Carpenter, 2000; Moschini et al.). The negligible yield effect is consistent with the argument that the simplicity and flexibility in pest management programs are key drivers of the rapid adoption of herbicide-tolerant soybeans (Fernandez-Cornejo and McBride, 2002).

Estimated Impacts on Pest Control Costs

Impacts of Bt and herbicide-tolerant technologies on cotton and soybean pest control costs include expenses associated with pesticide materials, application, scouting, and cultivation. Pest control costs for Bt cotton adopters were lower than for nonadopters in 1997. Regional differences in pest control cost savings were quite large, depending on the data source. For example, adopters' pest control costs averaged about 7 percent lower than for nonadopters in the Southern Seaboard, based on the estimated ARMS effects (table 5). These savings reached as high as 60 percent (based on the EMD) in the Southern Seaboard and 54 percent in the Mississippi Portal. While both data sources isolate the impact of biotechnology on insect-control costs, the divergent estimates are hard to reconcile. Computing the benefits from biotech adoption with the EMD is likely to result in much larger estimated benefits for U.S. farmers than with the estimated ARMS effects.

The estimated ARMS effect for pest control costs in the Southern Seaboard was calculated using elasticities that reflect the percentage change in pesticide use in response to a 1-percent increase in the adoption of biotech crops (Fernandez-Cornejo et al.). To illustrate, the first step is to estimate the expenses associated with pesticide active materials, ingredient by ingredient, used by nonadopters in a specific production region, such as the Southern Seaboard in the case of Bt cotton. Based on USDA's State-level chemical use data, the insecticide application rate per crop year and the percent of area applied with insecticides were tabulated by insecticide active ingredient at the regional level, as shown in table 6 (USDA, 1998a).

Insecticide active ingredients were grouped into three categories: organophosphates, pyrethroids, and other

Table 5—Impact of adopting Bt cotton on pest control costs by region and by data source, 1997

Production region	Adopters' differences in pest control costs from nonadopters Estimated ARMS effect	 EMD
	Percent	
Southern Seaboard	-7.08	-60.0
Fruitful Rim	n.a.	n.a.
Mississippi Portal	n.a.	-54.3
Eastern Uplands	n.a.	n.a.

n.a. = Not applicable. EMD = Enhanced Market Data II.

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[7] No estimated ARMS effects are available for Bt cotton yields in other production regions.

Figure 6

ERS crop production regions

🟥 **Basin and Range**

- Largest share of nonfamily farms, smallest share of U.S. cropland.
- 4% of farms, 4% of value of production, 4% of cropland.
- Cattle, wheat, and sorghum farms.

🟪 **Northern Great Plains**

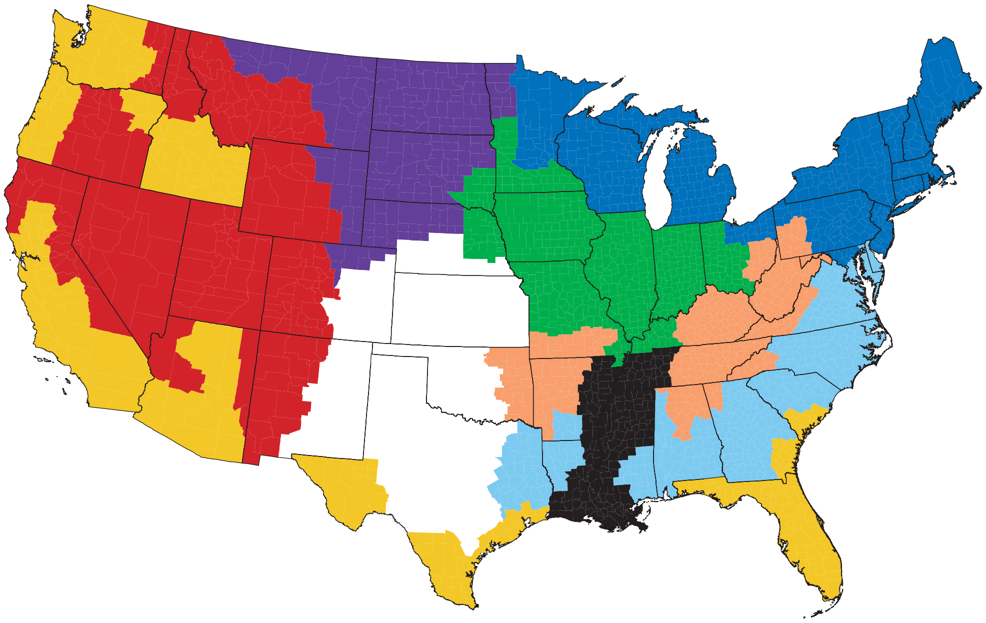
- Largest farms and smallest population.
- 5% of farms, 6% of value of production, 17% of cropland.
- Wheat, cattle, and sheep farms.

🟩 **Heartland**

- Most farms (22%), highest value of production, (23%), and most cropland (27%).
- Cash grain and cattle farms.

🟦 **Northern Crescent**

- Most populous region.
- 15% of farms, 15% of value of production, 9% of cropland.
- Dairy, general crop, and cash grain farms.



🟨 **Fruitful Rim**

- Largest share of large and very large family farms and nonfamily farms.
- 10% of farms, 22% of value of production, 8% of cropland.
- Fruit, vegetable, nursery, and cotton farms.

⬜ **Prairie Gateway**

- Second in wheat, oat, barley, rice, and cotton production.
- 13% of farms, 12% of value of production, 17% of cropland.
- Cattle, wheat, sorghum, cotton, and rice farms.

⬛ **Mississippi Portal**

- Higher proportions of both small and larger farms than elsewhere.
- 5% of farms, 4% of value of production, 5% of cropland.
- Cotton, rice, poultry, and hog farms.

🟦 **Southern Seaboard**

- Mix of small and larger farms.
- 11% of farms, 9% of value of production, 6% of cropland.
- Part-time cattle, general field crop, and poultry farms.

🟧 **Eastern Uplands**

- Most small farms of any region.
- 15% of farms, 5% of value of production, and 6% of cropland.
- Part-time cattle, tobacco, and poultry farms.

insecticides. Price data for insecticide active ingredients were obtained from USDA (1998c) and a database of 1996 prices developed by Gianessi and Marcelli, with some necessary conversions from the prices of final product to those of active-ingredient equivalents.

Multiplying the active ingredient prices by the individual weighting factors (application rate per crop year times the share of area applied) gives the per-acre expenses associated with each active ingredient for nonadopters. Adding up the per-acre expenses across active ingredients results in the total expense associated with insecticides—$20.48 per acre for nonadopters of Bt cotton in the Southern Seaboard. Including expenses for pesticide application, scouting, and cultivation (taken from the ARMS) increased the total insect control cost to $27.92 per acre for nonadopters in 1997.

Insecticide costs for adopters are estimated by accounting for potential savings in insecticide use, ingredient by ingredient. In the Southern Seaboard, the -0.21 elasticity for “other insecticides” means that adopters’ use of those materials was 21 percent lower than for nonadopters. Expenses associated with the “other insecticides” were $1.86 per acre lower for adopters in 1997 (table 6). No change occurred in the use of organophosphates and pyrethroids. In total, expenses for all insecticides equaled

Table 6—Insecticide costs for Bt cotton adopters versus nonadopters: Southern Seaboard, 1997

Insecticide active ingredient	Rate per crop year	Area applied	Weight	Price	Cost for nonadopters	Cost for adopters
	lb. per acre	*Percent*	*lb. per acre*	*$ per lb.*	*$ per acre*	
Organophosphates						
Malathion	n.a.	n.a.	n.a.	4.820	n.a.	n.a.
Methyl parathion	n.a.	n.a.	n.a.	6.825	n.a.	n.a.
Acephate	0.290	6.451	0.019	17.067	0.319	0.319
Phorate	0.833	9.828	0.082	10.700	0.876	0.876
Profenofos	0.633	1.963	0.012	12.400	0.154	.154
Dicrotophos	0.038	4.010	0.002	11.075	0.017	0.017
Subtotal					**1.212**	**1.212**
Pyrethroids						
Cypermethrin	0.128	10.303	0.013	91.636	1.204	1.204
Lambdacyhalothrin	0.062	42.758	0.027	231.270	6.157	6.157
Cyfluthrin	0.066	16.467	0.011	239.500	2.599	2.599
Zeta-cypermethrin	0.029	3.925	0.001	186.667	0.216	0.216
Tralomethrin	0.025	3.434	0.001	275.280	0.232	0.232
Fenpropathrin	n.a.	n.a.	n.a.	78.030	n.a.	n.a.
Subtotal					**10.408**	**10.408**
Other insecticides						
Aldicarb	0.716	43.327	0.310	24.667	7.654	6.047
Chlorpyrifos	n.a.	n.a.	n.a.	12.68	n.a.	n.a.
Oxamyl	n.a.	n.a.	n.a.	386.25	n.a.	n.a.
Endosulfan	n.a.	n.a.	n.a.	13.03	n.a.	n.a.
Dicofol	n.a.	n.a.	n.a.	29.14	n.a.	n.a.
Methomyl	0.319	3.365	0.011	26.519	0.284	0.225
Disulfoton	0.277	3.487	0.010	9.538	0.092	0.073
Esfenvalerate	0.043	5.993	0.003	224.242	0.581	0.459
Thiodicarb	0.378	3.925	0.015	16.620	0.246	0.195
Subtotal					**8.858**	**6.997**
Total insecticide costs					**20.478**	**18.618**
Application costs					**3.185**	**2.653**
Scouting costs					**4.261**	**4.761**
Total per-acre insect control costs					**27.924**	**26.032**

n.a. = Not applicable

Sources: Gianessi and Marcelli; USDA 1998a, 1998c.

$18.62 per acre for adopters, about 9 percent lower than for nonadopters. Including expenses for insecticide application and scouting brought the total pest control cost to $26.03 per acre for adopters, a savings of about 7 percent over nonadopters.

Herbicide-tolerant cotton shows no statistically significant impact on herbicide use nationwide, according to the estimated ARMS effect. However, adopters of this technology did realize gains through lower total weed control costs. Adopters in the Southern Seaboard, Mississippi Portal, and Prairie Gateway experienced a savings of 5-46 percent due to lower application, cultivation, and scouting expenses.

Similar to Bt cotton, weed control costs for herbicide-tolerant soybean adopters were lower than for non-adopters in 1997 (table 7). The savings realized by adopters ranged from about 1 percent to as much as 34 percent across production regions. This cost reduction is much smaller than in the study by Moschini et al. for 1999, which ranged from 49 percent to 66 percent (based on a reduction of $20 per hectare), depending on the number of additional glyphosate treatments applied.

Estimated ARMS effects for regional weed control costs are calculated in the same manner as for Bt cotton employing herbicide use elasticities (Fernandez-Cornejo et al.). A 1-percent increase in adoption leads

Table 7—Impact of adopting herbicide-tolerant soybeans on weed control costs, 1997

Production region	Estimated cost savings
	Percent
Heartland	-10.65
Northern Crescent	-12.21
Southern Seaboard	-3.91
Northern Great Plains	n.a.
Mississippi Portal	-4.45
Prairie Gateway	-0.89
Eastern Uplands	-33.92

n.a.= Not available.

Source: Estimated ARMS effects.

to a 0.43-percent increase in glyphosate use but a 0.14-percent decrease in the use of other synthetic herbicides. Expenses associated with the use of glyphosate were about $1.16 per acre higher for adopters in the Heartland (table 8). However, the decline in expenses associated with the use of other herbicides—$3.40 per acre—more than offset the increase in expenses for glyphosate. As a result, adopters' expenses for all herbicides totaled $25.64 per acre, versus $27.89 for nonadopters. Adopters of herbicide-tolerant soybeans in the Heartland are estimated to have realized a 10.7-percent ($3.50 per acre) savings in weed control costs when application, scouting, and cultivation expenses are considered along with herbicide costs.

Implications for Pesticide Use

Biotechnology led to reductions in pesticide use for Bt cotton in the Southern Seaboard, herbicide-tolerant cotton nationwide, and herbicide-tolerant soybeans in some major production regions. However, the reduction in pesticide use itself does not accurately measure total direct benefits to the environment and human health. Measuring herbicide use in pounds of active ingredients implies that, on a pound-for-pound basis, two ingredients have equal impacts. But in the case of herbicide-tolerant soybeans, other herbicides are replaced by glyphosate, which is less toxic and persistent than other herbicides (Heimlich et al.).

For Bt cotton, adoption clearly reduces insect control costs, but it also lowers the use of some insecticide active ingredients. While there is no compelling evidence showing that adopters' use of organophosphates and pyrethroids was lower, their use of "other insecticides" is estimated to be 21 percent lower than for nonadopters.

In contrast, the impact of adopting herbicide-tolerant soybeans on herbicide use is not as clear. While herbicide-tolerant soybeans lowered the use of "other herbicides" by 14 percent for adopters, adopters used 43 percent more glyphosate. Since average application rates vary across herbicide active ingredients, the net effect of substituting one herbicide for another may lead to an increase or a decrease in the total pounds of active ingredients used. Our analysis shows that the impact of adopting herbicide-tolerant soybeans on pesticide use was mixed—a net decline in the Heartland and Prairie Gateway but an increase in all other regions. Overall, the impact of herbicide-tolerant soybeans is a 3-percent increase in herbicide use (measured in pounds of active ingredients) nationwide in 1997.

The decline in herbicide use (in terms of active ingredients applied) for herbicide-tolerant soybean adopters in 1997 was limited to selected regions, ranging from 1.6 percent in the Heartland to 3.3 percent in the Prairie Gateway. For example, the use of glyphosate increased from 0.19 pound per acre for nonadopters to 0.27 pound per acre for adopters in the Heartland (table 8). In contrast, the use of "other herbicides" decreased from 0.70 pound per acre for nonadopters to 0.60 pound per acre for adopters. The end result was a decline in the use of all herbicides from 0.997 pound for nonadopters to 0.981 pound for adopters (a 1.6-percent reduction), which was lower than the 10.7-percent decrease in weed control costs for adopters. The increases in herbicide use in other regions were as follows: 8.4 percent, Northern Crescent; 11.7 percent, Mississippi Portal; and 10.9 percent, Southern Seaboard.

Table 8—Impact of herbicide-tolerant soybeans on herbicide use and weed control costs: Heartland, 1997

							Herbicide use	
Herbicide active ingredient	Rate per crop year	Area applied	Weight	Price	Cost for nonadopters	Costs for adopters	Nonadopters	Adopters
	lb. per acre	*Percent*	*lb. per acre*	*$ per lb.*	*$ per acre*		*lb. per acre*	
Acetamides								
Metolachlor	1.999	4.346	0.087	8.688	0.755	0.755	0.087	0.087
Alachlor	0.877	2.333	0.020	6.325	0.129	0.129	0.020	0.020
Subtotal					**0.884**	**0.884**	**0.107**	**0.107**
Glyphosate	0.710	26.807	0.190	14.175	**2.699**	**3.860**	**0.190**	**0.272**
Other herbicides								
Pendamethalin	1.074	29.479	0.317	8.909	2.820	2.425	0.317	0.272
Trifluralin	0.739	19.591	0.145	7.850	1.137	0.978	0.145	0.125
Bentaton	0.613	9.532	0.058	19.075	1.115	0.959	0.058	0.050
Clomazone	0.566	4.199	0.024	19.900	0.473	0.407	0.024	0.020
2, 4-D	0.372	9.567	0.036	3.725	0.133	0.114	0.036	0.031
Acifluorfen	0.140	8.338	0.012	28.920	0.338	0.291	0.012	0.010
Metribuzin	0.204	10.083	0.021	36.933	0.759	0.652	0.021	0.018
Imazethapyr	0.052	42.563	0.022	315.900	7.005	6.024	0.022	0.019
Sethodydim	0.154	8.009	0.012	67.333	0.833	0.716	0.012	0.011
Chlorimuron-thyl	0.030	13.868	0.004	1142.770	4.770	4.102	0.004	0.004
Clethodim	0.078	4.362	0.003	108.990	0.371	0.319	0.003	0.003
Dimethenamid	n.a.	n.a.	n.a.	14.23	n.a.	n.a.	n.a.	n.a.
Fenoxaprop	0.123	6.893	0.009	165.400	1.407	1.210	0.009	0.007
Fluazifop-P-butyl	0.048	7.774	0.004	64.830	0.242	0.208	0.004	0.003
Flumetsulam	0.055	1.915	0.001	n.a.	n.a.	n.a.	0.001	0.001
Flumiclorac Pentyl	0.020	1.292	0.000	215.830	0.055	0.047	0.000	0.000
Fomesafen	0.169	6.442	0.011	36.340	0.397	0.341	0.011	0.009
Imazamox	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Imazaquin	0.079	12.671	0.010	150.000	1.494	1.285	0.010	0.009
Lactofen	0.082	4.597	0.004	58.710	0.221	0.190	0.004	0.003
Linuron	0.053	0.089	0.000	24.000	0.001	0.001	0.000	0.000
Quizalofop-ethyl	0.035	2.533	0.001	143.190	0.128	0.110	0.001	0.001
Sulfentrazone	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Thifensulfuron	0.003	9.645	0.000	2084.320	0.503	0.432	0.000	0.000
Paraquat	0.273	1.912	0.005	14.470	0.075	0.065	0.005	0.004
Subtotal other herbicides					**24.276**	**20.877**	**0.698**	**0.600**
Adjusted subtotal (account for missing other herbicides)					**24.302**	**20.900**	**0.699**	**0.601**
Total herbicide use							**0.997**	**0.981**
Total herbicide material costs					**27.885**	**25.644**		
Application costs					**3.338**	**2.875**		
Scouting costs					**0.291**	**0.447**		
Cultivation costs					**1.267**	**0.314**		
Total weed control costs					**32.782**	**29.280**		

n.a. = Not applicable.

Sources: Gianessi and Marcelli; USDA 1998a, 1998c.

This study adopts the empirical model developed by Falck-Zepeda et al. (2000b) to estimate the economic gains for various stakeholders associated with the adoption of Bt and herbicide-tolerant cotton and herbicide-tolerant soybeans. Potential yield enhancements and savings in pest control costs are incorporated into models that derive each crop's supply shift resulting from biotechnology. Given domestic and export demands, counterfactual world prices and quantities demanded of the commodities—those that would have prevailed in the market if biotechnology had not been introduced—are determined from market equilibrium conditions. Producer and consumer surpluses in the United States and international markets are then estimated. Finally, monopoly profits accruing to the biotechnology developers and germplasm suppliers are calculated.

Because the biotech crops considered in this study are raw commodities, U.S. and ROW consumers include final consumers as well as intermediate buyers. For example, crushers buy soybeans to make soybean meal and soybean oil. Soybean meal is then sold to feed manufacturers as a protein supplement. Refined soybean oil can be used directly for food consumption or sold to food manufacturers. Final consumers benefit from buying products in which soybean meal and oil were used as inputs in the production processes. Thus, it is assumed that the price reduction caused by the shift in supply from biotechnology is shared among many buyers. The benefits to these buyers and final consumers will go to those who are indifferent to biotech versus nonbiotech foods.

Data and Assumptions

The empirical model makes use of data in which the effects of biotechnology on crop yields and pest control costs are isolated. The estimated ARMS effects were used in the cases of herbicide-tolerant cotton and soybeans nationwide as well as Bt cotton in the Southern Seaboard. Because of discrepancies in the reported farm-level effects, the EMD were also used in the analysis of Bt cotton (Southern Seaboard and Mississippi Portal only). This private sector data source provides another perspective on the likely range of estimated surplus changes from adopting Bt cotton.

The yield effects and changes in pest control costs assumed in this study vary by region (and by data source in the case of Bt cotton). This study considers four production regions for cotton and seven for soybeans (tables 4 and 7). Based on the estimated ARMS effects, 1997 Bt cotton yields were 21 percent higher for adopters than for nonadopters in the Southern Seaboard. The yield increase was smaller according to the EMD, ranging from 4 percent to 11 percent. Herbicide-tolerant cotton and soybean yields were 17 percent and 3 percent higher nationwide, according to the estimated ARMS effects.

Adopters of Bt cotton in the Southern Seaboard realized pest control expenses that were 7 percent lower than those of nonadopters, based on the estimated ARMS effect, and 60 percent lower with the EMD. In the case of herbicide-tolerant cotton, adopters' savings in pest control costs ranged from 5 percent to 46 percent. For herbicide-tolerant soybeans, the savings ranged from 1 percent to 34 percent, depending on the production region (table 7).

This study assumes that the efficiency of technology transfer to ROW producers equals 50 percent for Bt cotton and herbicide-tolerant soybeans. Technology transfer for herbicide-tolerant cotton was not considered because this biotech variety was only available in the United States in 1997.

Crop acreage data were obtained from USDA (1998b). Regional adoption data, as well as seed prices, premiums, and technology fees, were taken from the ARMS. Adopters' pest control costs were derived from the ARMS using pesticide use elasticities, application rates, and chemical prices. Commodity prices were estimated for each ERS crop production region using weighted State price data (USDA, 1998c).

While our estimation of the stakeholders' surpluses relies heavily on the Falck-Zepeda et al. (2000b) framework, a number of their assumptions were altered to better reflect commodity flows and trade patterns. Regional crop distribution data were used to determine the shares of production allocated to domestic use and exports (Glade et al.; Larson et al.). In addition, the assumption concerning the share of cotton imported by the rest of the world relative to its production was modified using data on ROW production and imports from USDA's *World Agricultural Supply and Demand Estimates* (USDA, 2000c).

The assumptions made in this study concerning U.S. and ROW supply and demand elasticities differ from those in previous analyses (table 2). In this analysis, regional domestic supply elasticities were taken from a recent study by Lin et al. (2000), which reflect the policy and market environments of the 1997 crop year (table 9). The U.S. cotton mill demand and net export demand elasticities were obtained from studies by Meyer and Duffy et al., respectively. The U.S. demand and shortrun net export demand elasticities for soybeans were estimated by Hyberg and Mercier. A longrun export demand elasticity of -1.36 estimated by Uri et al. supports the value reported by Hyberg and Mercier. Like Falck-Zepeda et al. (2000a), the ROW supply elasticities were taken from a study by Sullivan et al. Given the net export demand elasticities and ROW supply elasticities reported in the literature, the theoretically consistent ROW demand elasticities were computed for soybeans and cotton (Houck).

Key variables, including crop yields and pest control costs, were assigned probability distributions in this study.[8] Crop yields were assumed to be normally distributed. In any given season, some producers experience below-average yields while others achieve above-average yields. Most producers, however, have yields near the cross-sectional mean for a growing season. Seed, herbicide/insecticide, scouting, application, and cultivation costs were assumed to be lognormally distributed—a distribution that best fits the ARMS data. Including probability distributions in the simulations does not significantly alter the results in the cases of herbicide-tolerant cotton and soybeans. In contrast, the total estimated benefit associated with the adoption of Bt cotton is 2-3 percent higher with the probability distributions.

Table 9—Supply and demand elasticities assumed in this study

Parameter	1997 Bt and herbicide-tolerant cotton	1997 herbicide-tolerant soybeans
U.S. supply elasticity	0.47	0.28
U.S. demand elasticity	-0.50	-0.50
Net export demand elasticity	-0.97	-1.21
ROW supply elasticity	0.15	0.30
ROW demand elasticity	-0.15	-0.25

Mean Values of Estimated Marshallian Surplus Changes

Changes in Marshallian surplus estimates were computed using models that include data on regional adoption rates, crop yields, seed costs (including technology fees and premiums), pest control costs, supply and demand elasticities, commodity flows, and technology transfer to ROW producers. Welfare changes were then estimated for farmers and consumers in the United States and ROW (see Appendix A for mathematical details).

The models were simulated with a computer program, @RISK, to account for the probability distributions assigned to certain key variables. The software package randomly chose values from the probability distributions and calculated the stakeholders' welfare changes. The simulations were allowed to iterate 10,000 times. In the base scenario of this study, only the estimated mean surplus changes are reported. The mean values obtained from the simulations do not differ greatly from the point estimates calculated without the probability distributions.

Results for Bt Cotton

With the estimated ARMS effects, global benefits from adopting Bt cotton in 1997 were estimated at $212.5 million (table 10), with 78 percent of the surplus accruing to the United States. The estimated world benefit was $300.7 million with the EMD. These benefits accounted for 3.6-5.1 percent of the value of upland cotton production that year. Benefits received by U.S. farmers were estimated to range from $61.4 million (estimated ARMS effects) to $117.4 million (EMD). This range reflects the different assumptions concerning the extent of the technology's impacts on

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[8] The mean values of the estimated Marshallian surplus changes reported in this analysis were computed using point estimates for the U.S. and ROW supply and demand elasticities for all three biotech crops. Point estimates are used to foster transparency in identifying the driving forces that affect the models' simulation results and to avoid arbitrarily assigning minimum and maximum values for the probability distributions when supporting data (such as relevant standard errors of the regression coefficients) are not available.

Table 10—Estimates of world surplus changes for Bt cotton, 1997

Stakeholder	Estimated ARMS effect	EMD
	$ million	
U.S. farmers	61.4	117.4
U.S. consumers	29.9	50.4
Monsanto	62.0	62.0
Delta & Pine Land	12.9	12.9
ROW producers	-134.8	-233.4
ROW consumers	181.2	291.5
Net ROW	46.4	58.1
World benefit	212.5	300.7

EMD = Enhanced Market Data II.

crop yields and pest control costs. Greater savings in pest control costs in the Southern Seaboard and Mississippi Portal under the EMD were the driving force behind the larger estimated welfare gain for U.S. producers (table 5). U.S. farmers' share of the estimated world benefit ranged from 29 percent to 39 percent (fig. 7).

The estimated market benefits realized by the innovators—Monsanto (the biotechnology developer) and Delta & Pine Land (the germplasm supplier)—remain constant across the two data sources. The variables that affect their estimated benefits—including adoption rates, technology fees, and seed premiums—were fixed in 1997. Monsanto's estimated gain was determined primarily by the $32-per-acre technology fee (above and beyond the price premiums) that the company charged U.S adopters. Monsanto also collected the same technology fee on Mexico's 37,100 acres of Bt cotton. Adopters of the technology in Australia—where 165,000 acres were planted to that variety—were charged approximately $74 per acre.[9] Delta & Pine Land received a royalty payment of $5.11 per acre from Monsanto for the use of its parent germplasm (Falck-Zepeda et al., 2000b). In addition, Delta & Pine Land derived a portion of its estimated benefits from a $2-per-acre seed premium charged to U.S. adopters, accounting for 28 percent of the germplasm supplier's estimated surplus gain.[10]

Monsanto is estimated to have received $62.0 million in 1997 from the adoption of Bt cotton worldwide, while Delta & Pine Land's estimated benefit totaled $12.9 million (table 10). Regionally, the Mississippi Portal and Southern Seaboard provided the bulk of these estimated benefits (about $20 million each) because they are two major cotton-producing regions. The estimated benefits realized by the innovators remain constant across the two data sources because they are not dependent on the farm-level effects of biotechnology.

U.S. consumers (including cotton shippers, brokers, and mill buyers) are estimated to have received between $29.9 million (estimated ARMS effects) and $50.4 million (EMD) due to lower prices resulting from the adoption of Bt cotton. The world price of cotton was estimated to have declined 0.50 cents to 0.81 cents per pound (0.69-1.11 percent of the counterfactual world price—72.8 cents per pound) due to the introduction of the new technology, depending on the data source. U.S. consumers received a relatively small portion of the total estimated benefit, averaging 16 percent across the two data sources (fig. 7). This is not surprising, given that the insect resistance of Bt cotton is an input trait that primarily benefits producers through reduced yield losses and lower insect control costs.

Consumers and producers in the rest of the world were estimated to have realized a net market benefit of $46.4 million (estimated ARMS effects) to $58.1 million (EMD). The technology-induced increase in cotton supply lowered its world price, benefiting consumers. ROW producers, on the other hand, suffered welfare losses because most of them grew traditional varieties. Thus, they did not realize the cost savings associated with Bt cotton and were fully exposed to the reduction in the world price. ROW consumers and producers, on a net basis, obtained 19 percent (EMD) to 22 percent (estimated ARMS effects) of the estimated total world benefit (fig. 7).

Results for Herbicide-Tolerant Cotton

The size and distribution of market benefits associated with the adoption of herbicide-tolerant cotton were calculated using the estimated ARMS effects. The adoption of this technology resulted in an estimated global gain of $231.8 million in 1997, with the United States receiving 67 percent (table 11). This benefit represented 3.9 percent of the value of upland cotton pro-

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[9] Throughout this report, estimates of Monsanto's benefits are likely to be overstated because unknown administrative expenses, such as those associated with marketing and IPR enforcement, are not taken into account.

[10] No seed premiums were charged in other countries that year.

Figure 7

Percentage shares of the estimated total world surplus gain from adopting Bt cotton, 1997

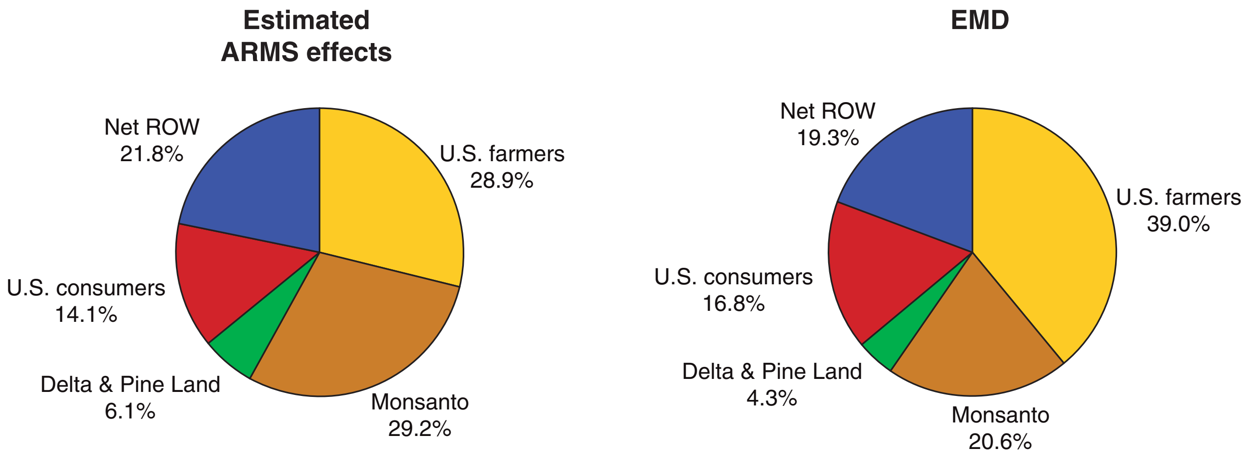
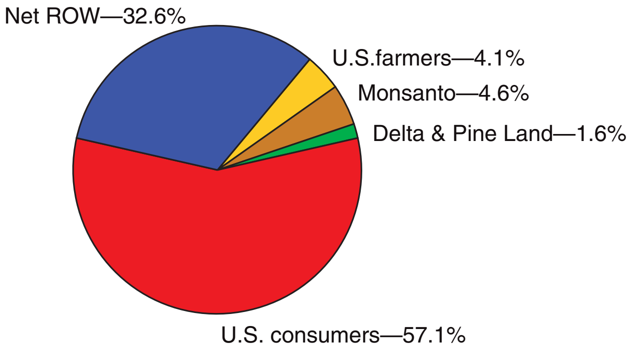


Table 11—Estimates of surplus changes for herbicide-tolerant cotton, 1997

Stakeholder	Estimated ARMS effects
	$ million
U.S. farmers	9.6
U.S. consumers	132.2
Monsanto	10.6
Delta & Pine Land	3.8
ROW producers	-733.3
ROW consumers	808.8
Net ROW	75.5
World benefit	231.8

Figure 8

Stakeholders' shares of the estimated total world benefit from adopting herbicide-tolerant cotton, 1997



duction that year. U.S. consumers were estimated to gain $132.2 million while ROW consumers realized an estimated benefit of $808.8 million. These benefits were due to higher yields that boosted cotton supply and lowered the world price by 2.5 cents per pound (3.4 percent of the counterfactual world price). This amount was much higher than the price effect from Bt cotton. In percentage terms, U.S. consumers captured the majority of the estimated benefits (fig. 8).

As with Bt technology, the herbicide-tolerant trait is geared to benefit adopters. However, U.S. farmers were estimated to have gained only $9.6 million from the adoption of herbicide-tolerant cotton. Greater seed costs (including seed premiums and technology fees) and the lower world cotton price offset much of the estimated benefits from higher yields, which were 17 percent higher for adopters nationwide. In 1997, the loan rate for upland cotton ($0.519 per pound) was lower than the world cotton price. Thus, U.S. cotton producers did not receive marketing loan gains or loan deficiency payments in that marketing year. The cotton loan program could affect the outcome in other years when loan rates are effective. U.S. farmers' share of the estimated total benefits was small—4 percent. The estimated benefits accruing to Monsanto and Delta & Pine Land were small as well.

ROW consumers were estimated to have gained $808.8 million from the adoption of herbicide-tolerant cotton, due exclusively to the decrease in the world price. ROW producers' estimated surplus fell in 1997 because they did not have access to the technology.

Thus, they were fully exposed to the falling world price without the benefits of higher yields and/or lower weed control costs. On a net basis, the ROW was estimated to have gained $75.5 million, or 33 percent of the total world benefit (fig. 8).

Results for Herbicide-Tolerant Soybeans

The gain in total world surplus from the adoption of herbicide-tolerant soybeans in 1997 was estimated at $307.5 million, with the United States capturing 94 percent of the estimated benefit (table 12). This benefit accounted for 1.7 percent of the value of soybean production that year. With the estimated ARMS effects, U.S. farmers received only 20 percent ($61.5 million) of the estimated total benefits (fig. 9). This small amount is due largely to the negligible percentage yield increase and small savings in weed control costs in major soybean-producing regions, which are consistent with other studies such as those by Gianessi and Carpenter (2000) and Duffy and Vontalge (table 7). While the farm-level effects were small in the case of herbicide-tolerant soybeans, adopters may have realized other benefits that are not quantified in this study, particularly those arising from simplified and flexible weed control programs and fewer restrictions on crop rotation, conservation tillage systems, and narrow-row plantings (Fernandez-Cornejo and McBride, 2002).

Monsanto’s estimated revenue ($85.6 million) from herbicide-tolerant soybeans was the result of a $7.25-per-acre technology fee charged to adopters.[11] This total is likely to be underestimated because it excludes the benefit of increased glyphosate sales resulting from the adoption of herbicide-tolerant soybeans. The total benefit estimated for germplasm suppliers ($124.4 million), which consisted of numerous seed companies, was derived from seed premiums that ranged from $1.58 to $8.47 per acre (the weighted average value was $4.31). The combined share of the estimated benefits (68 percent) captured by the innovators was large in 1997 due to the minimal farm-level effects for adopters (fig. 9).

Estimated benefits captured by Monsanto and the seed companies do not take into account the payments that licensing companies paid Monsanto for the use of the technology. When the herbicide-resistant trait was first developed for soybeans, Monsanto allowed some seed companies to purchase the technology outright for a fixed fee. Other firms were required to pay licensing fees. Because “use-of-technology” payment information is proprietary, it was not included in the calculation of the innovators’ benefits. To the extent that the seed companies made these payments to Monsanto, this study overstates the seed companies’ benefits and underestimates the gains that accrued to Monsanto.

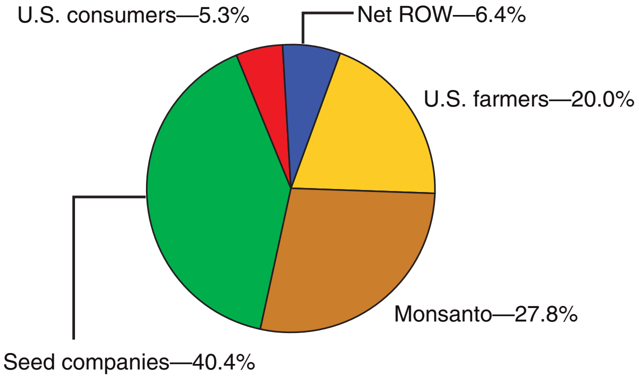
U.S. consumers benefited through increased soybean supply, which lowered the world price by 1.2 cents per bushel (0.17 percent of the counterfactual world price of $7.06 per bushel). Domestic consumers received only 5 percent of the estimated total benefit from herbicide-tolerant soybeans (fig. 9). Because U.S. producers realized only a modest net savings in pest control

Table 12—Estimates of surplus changes for herbicide-tolerant soybeans, 1997

Stakeholder	Estimated ARMS effects
	$ million
U.S. farmers	61.5
U.S. consumers	16.3
Monsanto	85.6
Seed companies	124.4
ROW producers	-35.0
ROW consumers	54.8
Net ROW	19.8
World benefit	307.5

Figure 9

Stakeholders' share of the estimated benefits resulting from adopting herbicide-tolerant soybeans, 1997



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[11] In 1997, the technology fee was $5 per 50-pound bag of herbicide-tolerant soybean seed. A 1.45 bag-per-acre seeding rate was assumed when calculating the technology fee on a per-acre basis.

costs, the price decrease for soybeans was modest. The minimal price change contributed to consumers' attaining only a small share of the estimated total benefit.

This study does not differentiate among consumers with different attitudes toward biotech foods. Even though U.S. consumers as a whole gained from the adoption of herbicide-tolerant soybeans, some consumers may have been negatively affected by the technology. Those who were indifferent to biotech versus nonbiotech foods benefited from the trait (because of slightly lower prices), but individuals who prefer but could not select nonbiotech foods faced a negative externality (Golan et al.).

ROW consumers were also estimated to have gained from the adoption of herbicide-tolerant soybeans, assuming consumer indifference to biotech versus nonbiotech foods. While the estimated net change in ROW surplus was positive, foreign producers suffered estimated losses. Except in Argentina, the adoption of herbicide-tolerant varieties outside of the United States was minimal in 1997.[12] As a result, most foreign producers faced lower world soybean prices without realizing the slight yield gains and reductions in weed control costs associated with herbicide-tolerant soybeans.

Comparison of Results With Previous Findings

The estimated total benefit ($212.5 million to $300.7 million) from Bt cotton (1997) in this study is generally greater than other studies' estimates. Direct comparison of this study's results with those covering other crop years is inappropriate due to year-specific factors, such as weather and pest infestation levels. The shares of the estimated benefits reported in this study appear to be lower for U.S. farmers and the innovators but higher for U.S. consumers and the rest of the world than in Falck-Zepeda et al. (2000a). In contrast, this study's findings differ significantly from Frisvold et al., who show that innovators and U.S. consumers received the bulk of the estimated total benefits. These discrepancies are largely attributed to differences in the model structure specified in the two studies, as well as supply and demand elasticity assumptions.

Our estimate of the total benefit ($307.5 million) resulting from the adoption of herbicide-tolerant soybeans is significantly lower than the $1.1 billion reported by Falck-Zepeda et al. (2000a) under the low U.S. supply-elasticity scenario (table 3). In addition, their study shows a much larger share of the estimated benefits for U.S. farmers (due, in part, to larger yield enhancement effects assumed in their study), but lower shares for innovators and U.S. consumers. For example, U.S. farmers realized 77 percent of the estimated total benefit ($808 million) in their study, while this study shows only $62 million to U.S. farmers, or 20 percent.

It is difficult to compare this study's results for herbicide-tolerant soybeans with those of Moschini et al. First, their study explicitly includes soybean-processed products as well as soybeans, while our study is limited to soybeans only. Second, the two analyses cover different years—1999 versus 1997. Third, the analytical frameworks and elasticity assumptions differ. While this analysis shows a considerably smaller estimated total benefit than the $804 million in Moschini et al., the shares of the estimated benefits that accrued to U.S. farmers (about 20 percent) are comparable across the two studies.

Measuring the benefits arising from the adoption of biotechnology depends on a number of factors. The results are affected by the choice of the analytical framework, particularly with respect to the nature of U.S. and ROW supply curves (linear versus nonlinear) and the shift in supply (parallel versus nonparallel). In addition, different supply and demand elasticity assumptions could influence both the size and distribution of estimated benefits.

Although there are differences in the theoretical frameworks of Falck-Zepeda et al. (2000b) and Moschini et al., their separate approaches can be reconciled by equalizing certain assumptions. Appendix B demonstrates that by using identical U.S. and ROW supply and demand elasticities as well as the same farm-level effects, stakeholders' estimated benefits are generally convergent, regardless of differences in the frameworks. This suggests that the choices of linear or nonlinear supply and demand functions and parallel or nonparallel supply shifts are not as critical in affecting the size and distribution of benefits as the U.S. and ROW supply elasticities and the magnitude of farm-level effects associated with the new technologies.

The size of the surplus gains hinges on the scope of the analysis, particularly with regard to which market

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[12] Approximately 3.5 million acres of herbicide-tolerant soybeans were planted in Argentina and 2,500 acres in Canada in 1997, while 11.8 million acres were planted in the United States (James).

benefits are considered and whether nonmarket benefits are included in the analysis. This study is limited to certain market benefits that accrue to various stakeholders. Market benefits that are not quantified in this study, but may be significant, include ease of pest management in the case of herbicide-tolerant soybeans, the insurance value associated with insect-resistant crops like Bt cotton, and fuel savings from fewer pesticide applications (Fernandez-Cornejo and McBride, 2002). It is widely recognized that the first benefit has driven the rapid adoption of herbicide-tolerant soybeans by U.S. farmers. Moreover, the importance of nonmarket benefits, such as impacts on the environment and human health, is crucial but not quantified here. Year-specific variables, such as weather and pest pressures, also influence the size of the market benefits and their distribution.

The size and distribution of market benefits also depend on the type of new biotech traits. Bt and herbicide-tolerant technologies, which are the focus in this study, are input traits and directly benefit producers through potential yield enhancements and/or savings in pest control costs. In contrast, crops with output traits, which are still in development, are geared to benefit consumers more directly.

Last, the benefits arising from the adoption of biotech crops depend on who develops the technologies. Most commercially available biotech crops to date have been developed by the private sector through research and development efforts that are typically protected by intellectual property rights, such as patents. Technology fees are necessary to recoup research and development costs that are incurred by these private firms. Thus, the benefits to producers and consumers are reduced under the private development scenario because the private firms are able to extract monopoly profits through technology fees. In contrast, public sector development (such as by land-grant universities and government research agencies) leads to greater benefits for producers and consumers than in the private development scenario for two reasons: (1) producers are not likely to be charged technology fees, and (2) the innovations are likely to be public goods, which benefit consumers (Smith et al.).

The comparison of benefits from biotechnology with those of nonbiotech innovations in earlier years is difficult. Previous studies on the benefits of adopting agricultural nonbiotech innovations focus on public sector investment and the distribution of benefits between producers and consumers. Public sector research, particularly in the area of self-pollinated seeds, has historically been difficult for private inventors to appropriate—not only because the products are reproducible, but also because most biological inventions, until recently, were not subject to standard patent law (Smith et al.). Thus, agricultural research was unlikely to attract adequate private investment because the prospects for financial returns were low.

However, recent developments in patent laws and the potential to earn monopoly profits spurred greater interest in private sector development, including the area of biotechnology. (The Plant Variety Protection Act, enacted in 1970 and amended in 1994, provides IPR protection to developers of new plant varieties that are sexually reproduced by seed, and utility patent protection for plant innovations was explicitly extended by 1985.) Studies that look at biotech innovations consider the benefits that accrue to producers, consumers, and innovators, while studies that focus on nonbiotech innovations have nearly always been limited to the benefits to producers and consumers (and, in a few cases, processors as well) (Alston, Norton, and Pardey; Alston, Sexton, and Zhang).

Sensitivity Analysis

Our estimated benefits from the adoption of three biotech crops in 1997 represent base scenarios that assume a set of supply and demand elasticities as well as specific farm-level effects realized by ROW producers. However, uncertainty surrounding the values of these parameters warrants sensitivity analyses to determine how the results may differ in response to changes in these parameters. In addition, we tackle uncertainty surrounding the estimated stakeholder benefits by showing the percentile distributions of the estimated surplus gains for the three crops.

Supply and Demand Elasticity Assumptions

To gauge the extent to which different supply and demand elasticities affect surplus estimates, the elasticity values in the base scenarios were adjusted for each biotech crop. In total, there were four alternate scenarios for each crop. The benefits were computed with U.S. and ROW supply elasticities that are (a) double their original values and (b) half their original values. Likewise, stakeholders' benefits were computed with U.S. domestic and net export demand elasticities, as well as a ROW demand elasticity, that are (a) double their original values and (b) half their original values.

The sensitivity analysis indicates that changes in the supply elasticities (especially for the United States) have a dramatic effect on estimated total surplus gains (figs. 10-12). For example, the increase in estimated world welfare associated with Bt cotton adoption (using the estimated ARMS effects) is 74 percent higher than in the base case when the U.S. and ROW supply elasticities are cut in half. In contrast, the estimated total benefit is 37 percent smaller when the supply elasticities are doubled (fig. 10).

The estimated benefits that accrue to U.S. farmers greatly depend on the values of the supply elasticities. For example, variations in supply elasticities produce dramatic changes in the estimated surplus for U.S. soybean producers. With smaller values, U.S. farmers would have realized an estimated surplus gain ($301.5 million) that is nearly 5 times as large as in the base case (fig. 12). In contrast, U.S. farmers would have incurred an estimated welfare loss with higher supply elasticities.

U.S. producers' share of the estimated total benefits is also affected by the magnitude of the supply elasticities, particularly for Bt cotton and herbicide-tolerant soybeans (fig. 13). Doubling the supply elasticities causes U.S. soybean producer's share to disappear. Lowering supply and demand elasticities results in higher benefit estimates for U.S. consumers and the net ROW. Because the factors (e.g., adoption rates, technology fees, and seed premiums) that determine the innovators' benefits are fixed in the model for a given crop year, their estimated welfare gains remain unchanged as the supply and demand elasticities are adjusted.

Figure 10

Sensitivity of benefit estimates to changes in supply elasticities: Bt cotton (estimated ARMS effects)

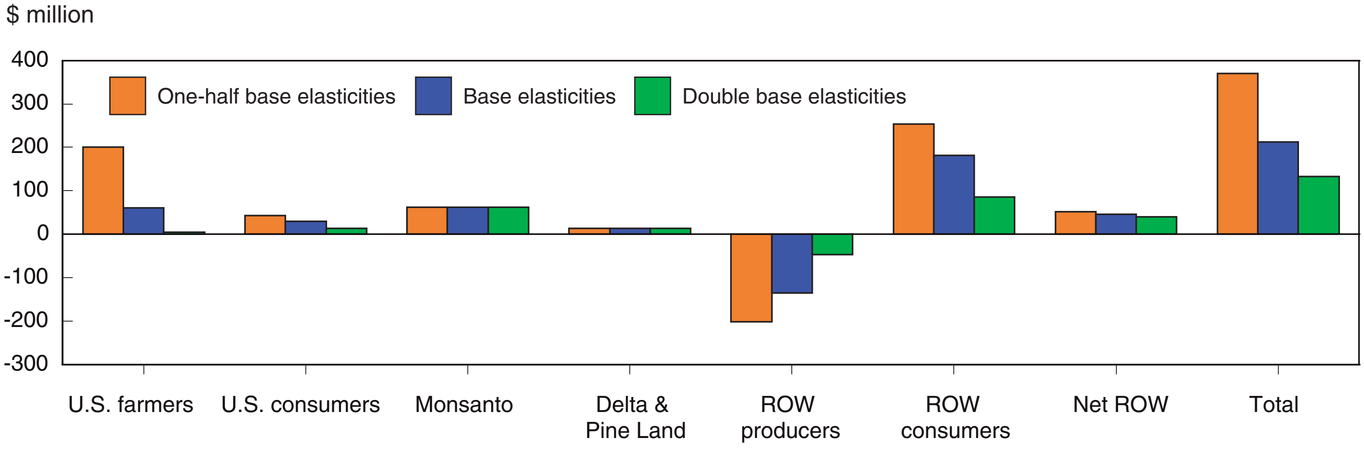


Figure 11

Sensitivity of benefit estimates to changes in supply elasticities: Herbicide-tolerant cotton

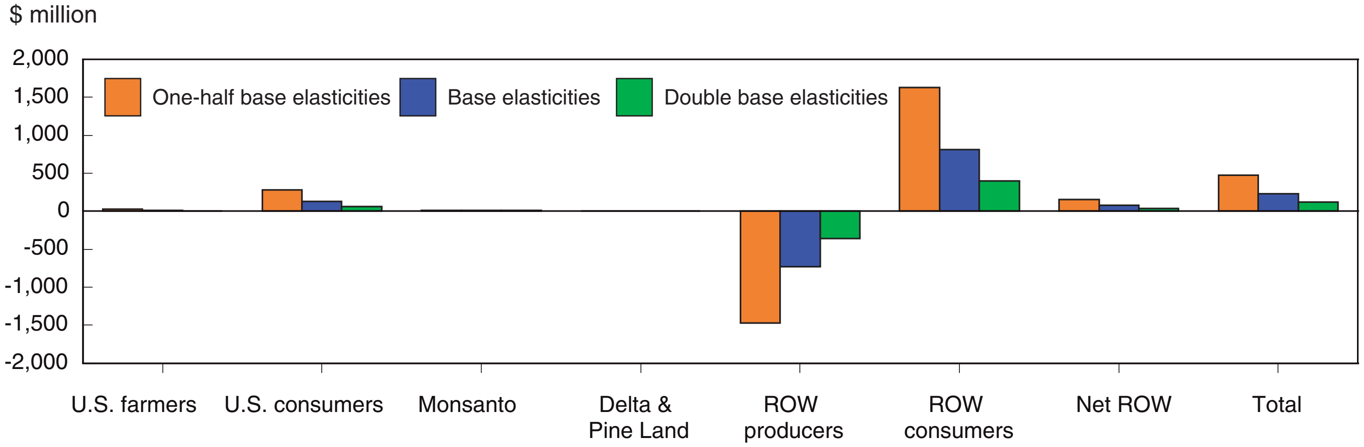


Figure 12

Sensitivity of benefit estimates to changes in supply elasticities: Herbicide-tolerant soybeans

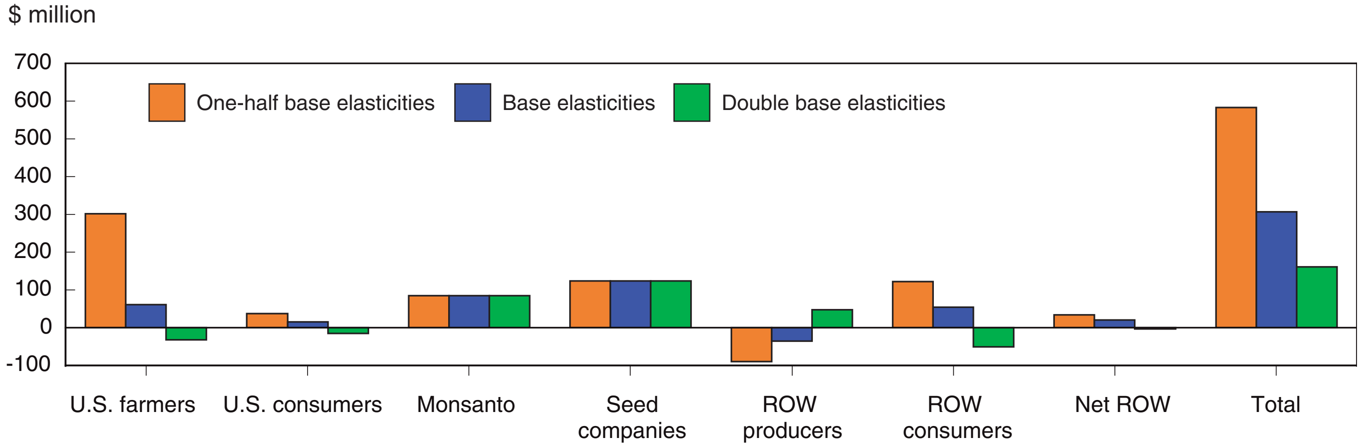
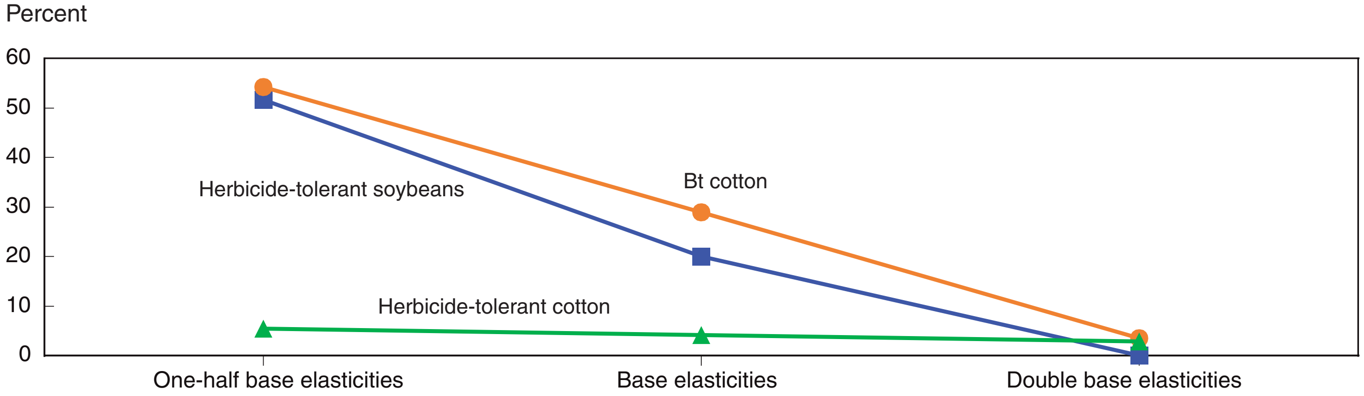


Figure 13

Sensitivity of U.S. farmers' share of estimated surplus gain to changes in U.S. and ROW supply elasticities



Altering the demand elasticities leads to more modest changes in estimated total benefits for the three crops and smaller changes in estimated producer and consumer surpluses (figs. 14-16). For example, given inelastic supply and demand, the estimated U.S. consumer surplus increases slightly and U.S. producer surplus falls slightly when the U.S. demand becomes even more inelastic. If U.S. supply becomes more inelastic, the estimated U.S. producer surplus becomes considerably larger. Sensitivity analysis of the EMD benefit estimates produces the same results.

Efficiency of Technology Transfer

In this sensitivity analysis, the base assumption for efficiency of technology transfer is varied to encompass "low" and "high" farm-level impacts in the ROW. Specifically, ROW producers are hypothesized to have realized either 10 percent (the low-efficiency case) or 100 percent (the high-efficiency case) of the technologies' impacts on crop yields and pest control costs, as compared with 50 percent in the base scenario. The efficiency assumption was not considered for herbicide-tolerant cotton since that variety was not commercially available to ROW producers in 1997. About 30 percent of Bt cotton was grown outside of the United States in 1997—mostly in Australia and South Africa (James). For soybeans, about 23 percent of the herbicide-tolerant variety was produced in the ROW, primarily in Argentina.

The estimated total world surplus would increase as a result of a more efficient transfer of technology, with

Figure 14

Sensitivity of benefit estimates to changes in demand elasticities: Bt cotton (estimated ARMS effects)

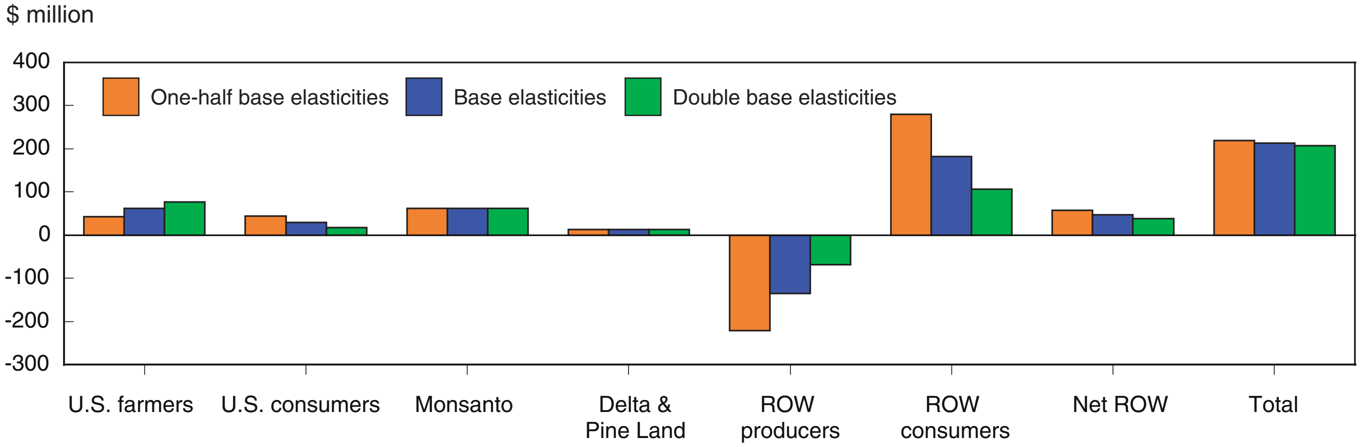


Figure 15

Sensitivity of benefit estimates to changes in demand elasticities: Herbicide-tolerant cotton

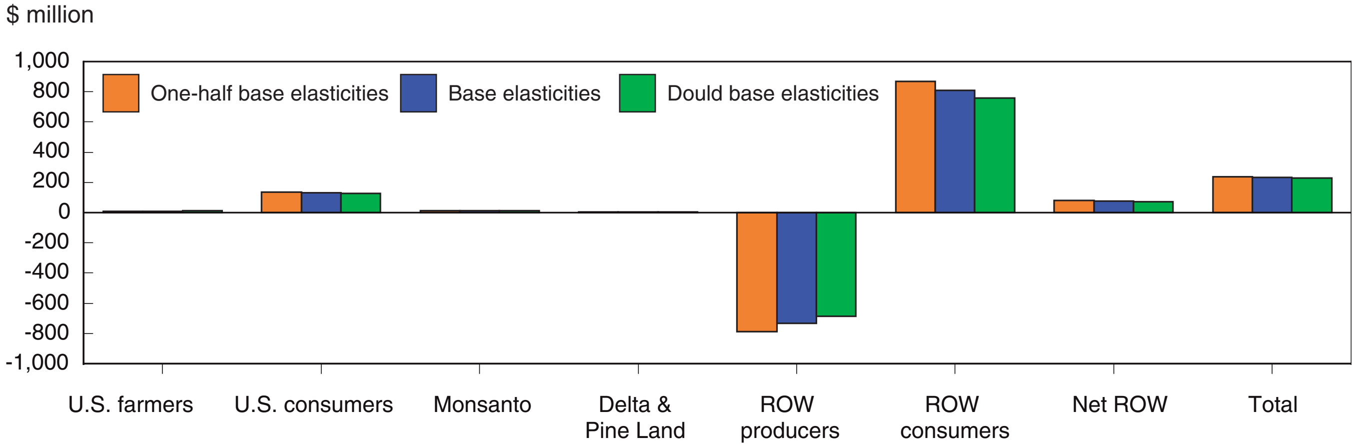
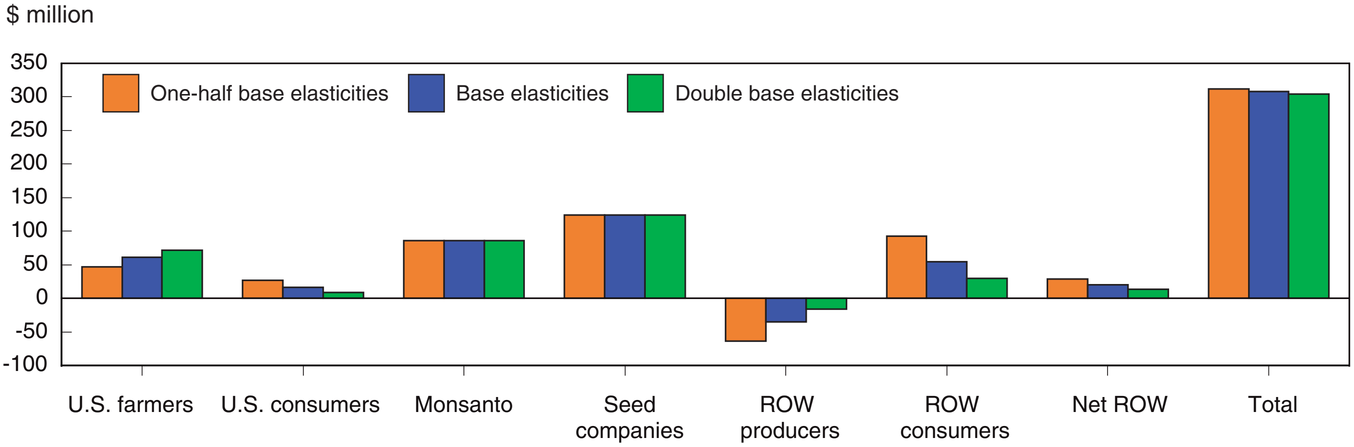


Figure 16

Sensitivity of benefit estimates to changes in demand elasticities: Herbicide-tolerant soybeans



the gains almost entirely in the ROW (figs. 17-18). While ROW producers would still incur a welfare loss, their higher yields and greater savings in pest control costs would mitigate some of the loss caused by greater supply and a lower world price. As a consequence of the downward pressure on cotton prices, U.S. farmers would experience a slightly lower estimated welfare gain. In contrast, U.S. and ROW consumers would benefit from lower prices.

Range of Estimated Surplus Gains or Losses

Variability in parameter values for certain key variables leads to estimated stakeholder benefits that are dispersed around the estimated mean values. The degree of variability for these parameters is incorporated in the @Risk simulations through assumed probability distributions.

The estimated total benefit resulting from the adoption of Bt cotton varies widely, especially when the EMD are used (fig. 19). With that data source, there is a 50-percent probability that the estimates of the total welfare change will fall between a loss of $217 million (25th percentile) and a gain of $817 million (75th percentile). This large dispersion is due primarily to variation in the estimated benefits that accrue to U.S. farmers and the net ROW. The ranges of the benefit estimates are smaller for all stakeholders (except the innovators) when the estimated ARMS effects are employed (fig. 20).

In the case of herbicide-tolerant cotton, there is little variation in the estimated benefits that accrue to U.S. farmers and consumers, due largely to the use of point estimates for regional savings in pest control costs (fig. 21). The dispersion in the estimated total benefits ($169 million to $294 million) mirrors the variability in estimated welfare gains realized by the ROW (on a net basis). Relative to herbicide-tolerant cotton, the estimated surplus gains from herbicide-tolerant soybean adoption are more variable for U.S. farmers and the rest of the world (fig. 22). The innovators' estimated surplus gains are not constant for herbicide-tolerant cotton and soybeans because the estimates use variables that have probability distributions assigned to them.

Figure 17

Sensitivity of benefit estimates to changes in the efficiency of technology transfer: Bt cotton (estimated ARMS effects)

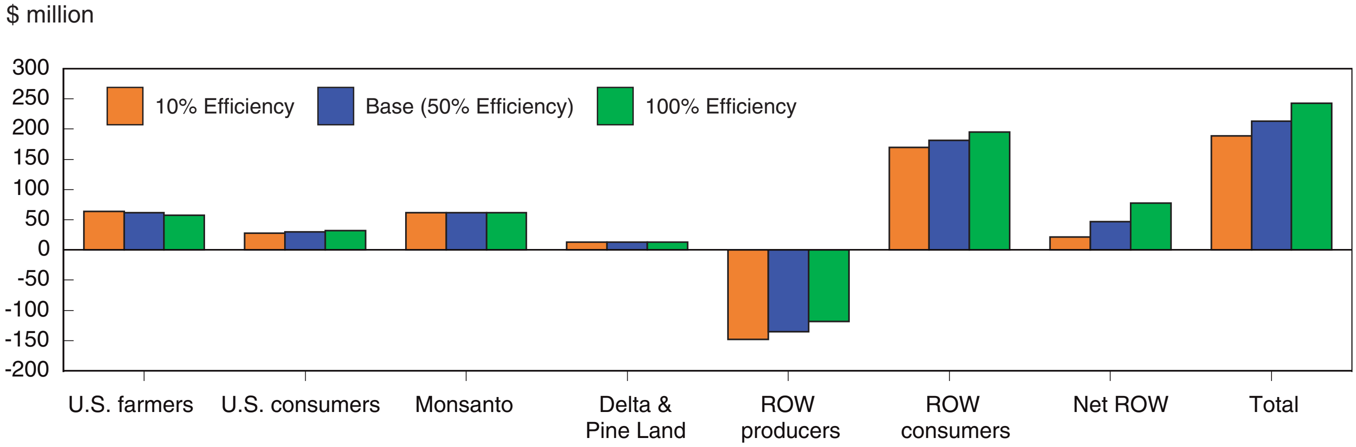


Figure 18

Sensitivity of benefit estimates to changes in the efficiency of technology transfer: Herbicide-tolerant soybeans

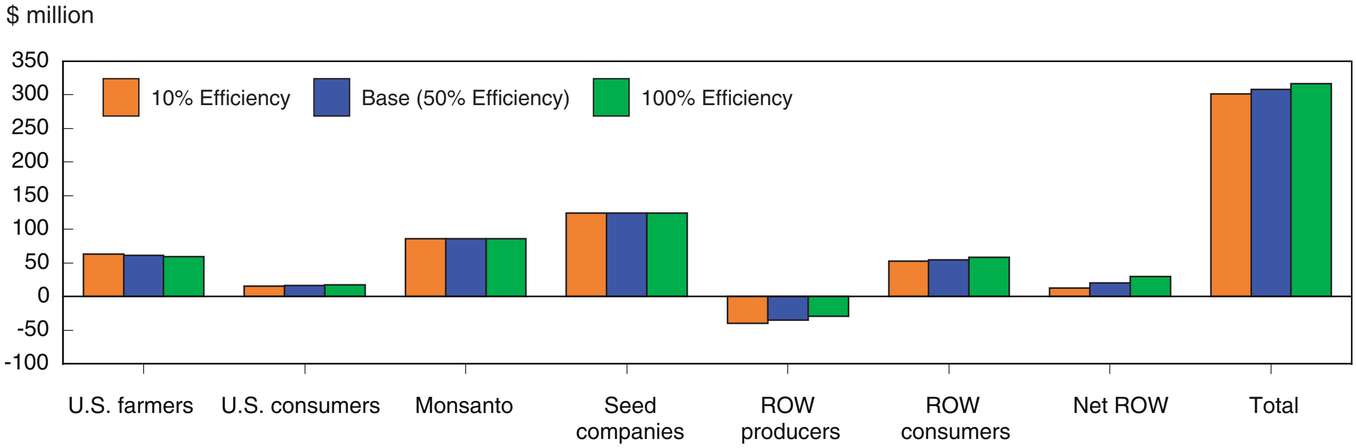


Figure 19

Dispersion of benefit estimates: Bt cotton (EMD)

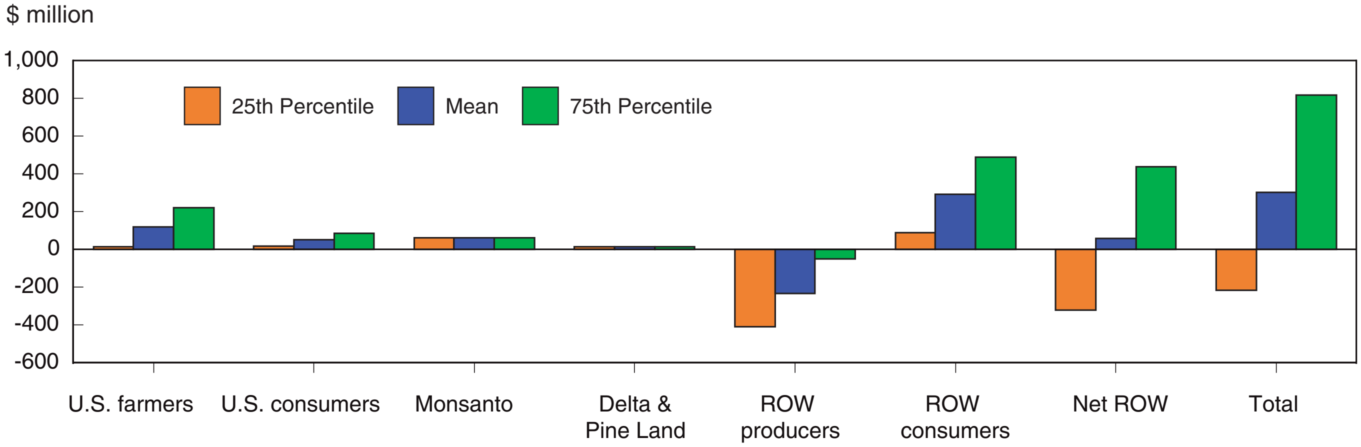


Figure 20

Dispersion of benefit estimates: Bt cotton (estimated ARMS effects)

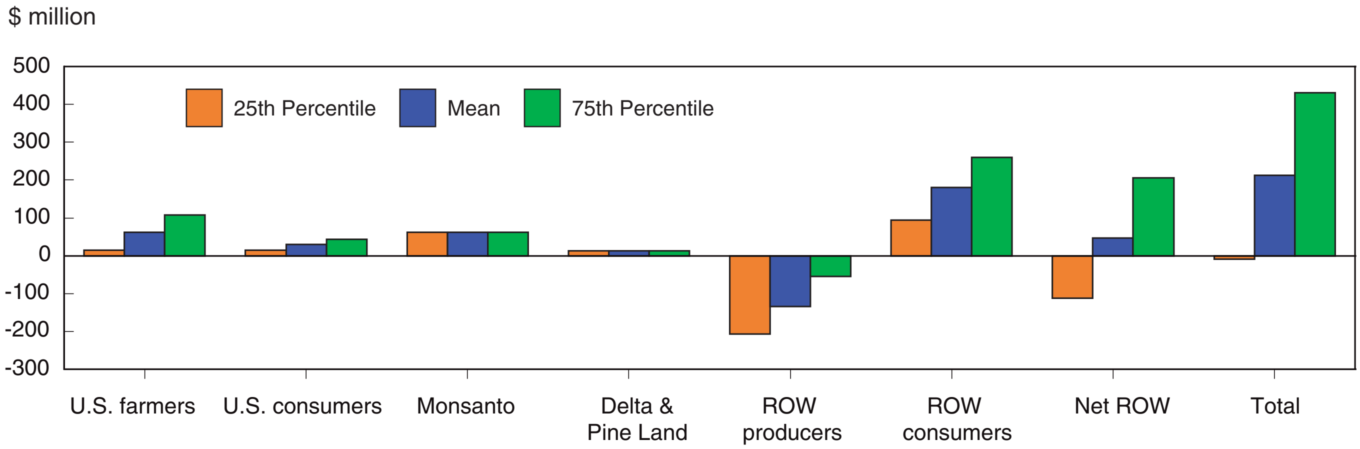


Figure 21

Dispersion of benefit estimates: Herbicide-tolerant cotton

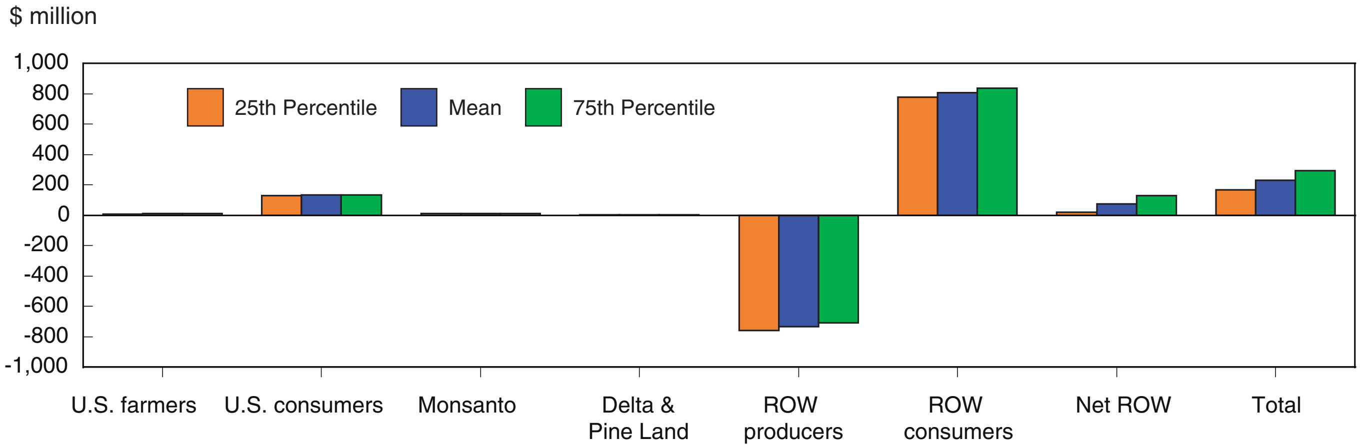
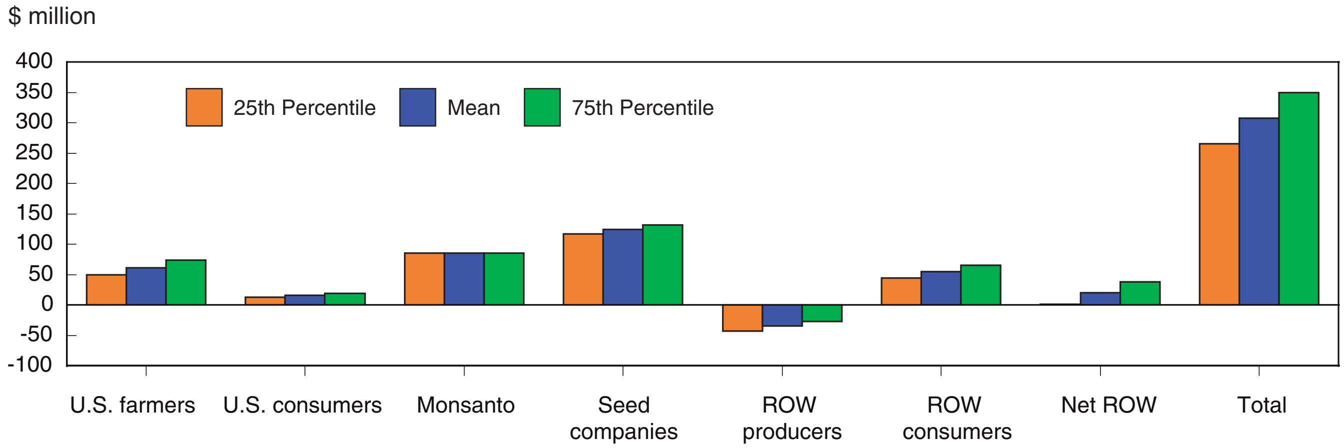


Figure 22

Dispersion of benefit estimates: Herbicide-tolerant soybeans



Conclusions

The estimated total benefit arising from the adoption of three biotech crops in 1997 varied significantly across crops, ranging from $213 million to $301 million for Bt cotton (depending on the data source) to $308 million for herbicide-tolerant soybeans. The adoption of herbicide-tolerant cotton resulted in an estimated total gain of $232 million. This study's estimate of the total benefit from adopting Bt cotton exceeds those of other studies that consider the 1997 crop. In contrast, the estimate of the total benefit for herbicide-tolerant soybeans lies toward the lower end of the range reported in previous analyses.

While a number of previous studies have estimated that U.S. producers obtain about half of the estimated total benefits, this analysis finds that they received about a third or less in 1997. Past estimates of U.S. producers' benefit shares vary widely in the case of herbicide-tolerant soybeans, ranging from 20 percent to 77 percent. In this study, the share of the estimated benefits that accrued to domestic soybean producers is at the lower end of that range. U.S. producers received a small portion of the estimated benefits from herbicide-tolerant cotton; modest savings in pest control costs did not compensate for losses resulting from lower market prices.

This analysis finds that innovators received 30 percent (average of the results from the estimated ARMS effects and EMD) of the estimated total benefits arising from Bt cotton adoption, a value generally lower than in other studies. In contrast, innovators captured 68 percent of the estimated benefits from herbicide-tolerant soybeans, considerably higher than previous estimates. In the cases of these two biotech crops, U.S. consumers received a small share of the estimated total benefits (5 percent to 17 percent), a result comparable with other studies. With herbicide-tolerant cotton, 57 percent of the estimated benefits accrued to U.S. consumers because of lower commodity prices.

Considerable uncertainty surrounds the estimates of total benefits arising from the adoption of biotechnology. Of the three crops, Bt cotton has the widest dispersion of estimated total benefits, ranging from -$9 million to $431 million with the estimated ARMS effects, compared with the mean of $213 million. The dispersion of estimated total benefits appears to be smaller for both herbicide-tolerant cotton and soybeans. Estimated total benefits—as well as the shares that accrue to the various stakeholders—are sensitive to the choice of analytical framework, particularly with respect to the nature of the U.S. and ROW supply curves (linear versus nonlinear) and the shift in supply (parallel versus nonparallel). Results also depend on assumptions concerning the U.S. and ROW supply and demand elasticities. The sensitivity analysis shows that altering the U.S. and ROW supply elasticities has a bigger impact on the estimated stakeholder benefits than changing the demand elasticities.

Many other factors, which are not quantified in this study, influence the size and distribution of benefits stemming from biotech adoption. Stakeholder benefits depend on the extent to which both market and nonmarket benefits are included in the analysis. This study captures only certain market benefits, disregarding the convenience value of simplicity and flexibility in weed control programs and the insurance value of crop protection associated with insect-resistant crops. Given the minimal farm-level effects associated with herbicide-tolerant soybeans, ease of pest management is regarded as the primary reason behind the rapid adoption of this technology by U.S. farmers.

Neither does this study fully consider nonmarket benefits, such as impacts on the environment and human health, which may be significant. Biotechnology led to reductions in pesticide use (measured in pounds of active ingredients) for Bt cotton in the Southern Seaboard, herbicide-tolerant cotton nationwide, and herbicide-tolerant soybeans in some major production regions. However, analyzing changes in pesticide use alone does not accurately measure the total direct benefits to the environment and human health.

First generation biotech crops have had input trait characteristics, such as insect resistance, that primarily benefit producers. As biotech crops with output traits are developed, they could directly benefit consumers. In addition, the benefits arising from the adoption of biotech crops depend on who develops the technologies. If biotech crops were to be developed by the public sector, the technologies would likely be public goods. As a result, consumers may capture a greater proportion of the benefits.

Last, benefits from biotech crops are dependent on year-specific and crop-specific factors, such as weather and pest infestation levels. This suggests that multiyear analyses and analyses of other crops, such as corn, would yield a more accurate perspective on the size and distribution of benefits resulting from the adoption of agricultural biotechnology. This extended analysis will be particularly relevant with increased technology transfer to the ROW, the emergence of several competing biotechnology varieties for some crops, and evolving pest management requirements for Bt products that may affect pesticide use.

References

Alston, J. M., G. W. Norton, and P. G. Pardey. *Science Under Scarcity: Principles and Practice for Agricultural Research Evaluation and Priority Setting*. Cornell University Press: Ithaca, NY, 1995

Alston, J. M., R. J. Sexton, and M. Zhang. "The Effects of Imperfect Competition on the Size and Distribution of Research Benefits," *American Journal of Agricultural Economics* 79(1997): 1252-1265

Carpenter, J., and L. Gianessi. "Case Study in Benefits and Risks of Agricultural Biotechnology: Roundup Ready Soybeans." National Center for Food and Agricultural Policy, Washington, DC, 2000.

_____. "Herbicide Tolerant Soybeans: Why Growers are Adopting Roundup Ready Varieties," *AgBioForum* 2(1999a): 65-72.

_____. "Why U.S. Farmers are Adopting Genetically Modified Crops," *Economic Perspectives*, October 1999b.

Duffy, M., and A. Vontalge. "Estimated Costs of Crop Production in Iowa 1999." Iowa State University Extension, Fm-1712, January 1999.

Duffy, P. A., M. K. Wohlgenant, and J. W. Richardson. "The Elasticity of Export Demand for U.S. Cotton," *American Journal of Agricultural Economics* 72(1990): 468-474.

Ervin, D. E., S. S. Batie, R. Welsh, C. L. Carpentier, J. I. Fern, N. J. Richman, and M. A. Schultz. *Transgenic Crops: An Environmental Assessment*. Policy Studies Report No. 15, Henry A. Wallace Center for Agricultural & Environmental Policy, Winrock International: Arlington, VA, January 2001.

Falck-Zepeda, J. B., G. Traxler, and R. G. Nelson. "Rent Creation and Distribution from the First Three Years of Planting Bt Cotton." ISAAA Briefs No. 14. International Service for the Acquisition of Agri-biotech Applications: Ithaca, NY, 1999.

_____. "Rent Creation and Distribution from Biotechnology Innovations: The Case of Bt Cotton and Herbicide-Tolerant Soybeans in 1997," *Agribusiness* 16(2000a): 21-32.

_____. "Surplus Distribution from the Introduction of a Biotechnology Introduction," *American Journal of Agricultural Economics* 82(2000b): 360-369.

Fernandez-Cornejo, J., and W. McBride. *Genetically Engineered Crops for Pest Management in U.S. Agriculture: Farm-Level Effects*. AER-786, U.S. Dept. Agr., Econ. Res. Serv., April 2000.

_____. "Genetically Engineered Crops: U.S. Adoption and Impacts," *Agricultural Outlook*, AGO-294, September 2002.

Fernandez-Cornejo, J., C. Klotz-Ingram, and S. Jans. "Farm-Level Effects of Adopting Genetically Engineered Crops in the U.S.A." in W.L. Lesser (ed.), *Transitions in Agrobiotech: Economics of Strategy and Policy*. Proceedings of the 1999 NC-165 Conference in Washington DC, June 24-25, 1999. Food Marketing Research Center, University of Connecticut and Dept. Resource Economics, University of Massachusets: Amherst, MA, 2000, pp. 57-72.

Frisvold, G., R. Tronstad, and J. Mortensen. "Effects of Bt Cotton Adoption: Regional Differences and Commodity Program Effects." Paper presented at the Western Agricultural Economics Association Meeting, Vancouver, Canada, June 30, 2000.

Gianessi, L. P. Statement before the U.S. Environmental Protection Agency Science Advisory Panel on Bt Plant Pesticides: Risk and Benefits Assessments. Washington, DC, October 20, 2000.

Gianessi, L. P., and J. E. Carpenter. "Agricultural Biotechnology: Insect Control Benefits." National Center for Food and Agricultural Policy, Washington, DC, 1999.

____. "Agricultural Biotechnology: Benefits of Transgenic Soybeans." National Center for Food and Agricultural Policy, Washington, DC, April 2000.

Gianessi, L. P., and M. B. Marcelli. "Prices of Pesticide Active Ingredients (1996)." National Center for Food and Agricultural Policy, Washington, DC, October 1996.

Gianessi, L. P., C. S. Silvers, S. Sankula, and J. E. Carpenter. Plant Biotechnology: *Current and Potential Impact for Improving Pest Management in U.S. Agriculture, An Analysis of 40 Case Studies*. National Center for Food and Agricultural Policy, Washington, DC, June 2002.

Gibson, J. W., D Laughlin, R. G. Luttrell, D. Parker, J. Reed, and A Harris. "Comparison of Costs and Returns Associated with *Heliothis* Resistant Bt Cotton to Non-resistant Varieties," *Proceedings of the Beltwide Cotton Conference*, vol. 1, P. Dugger and D. Richter, eds. Memphis, TN: National Cotton Council of America, 1997.

Glade, E. H., Jr., M. D. Johnson, and L. A. Meyer. *U.S. Cotton Distribution Patterns, 1993/94*. SB-940, U.S. Dept. Agr., Econ. Res. Serv., 1997.

Golan, E., F. Kuchler, and L. Mitchell. *Economics of Food Labeling*. AER-793, U.S. Dept. Agr., Econ. Res. Serv., December 2000.

Heimlich, R. E., J. Fernandez-Cornejo, W. McBride, C. Klotz-Ingram, S. Jans, and N. Brooks. "Genetically Engineered Crops: Has Adoption Reduced Pesticide Use?" *Agricultural Outlook* AGO-273, August 2000.

Houck, J. P. *Elements of Agricultural Trade Policy*. Macmillan: New York, NY (1986).

Huffman, W.E. "Economics of Intellectual Property Rights in Plant Materials," Presented at a conference for U.S. Plant Patent Examiners, Ames. IA. September 2, 1992.

James, C. "Global Review of Commercialized Transgenic Crops: 1998." *ISAAA Briefs* No. 8. International Service for the Acquisition of Agribiotech Applications: Ithaca, NY, 1998.

Larson, D. W., T. R. Smith, and E. D. Baldwin. *Soybean Movements in the United States: Interregional Flow Patterns and Transportation Requirements in 1985*, Agricultural Experiment Station, University of Illinois at Urbana-Champaign, September 1990.

Lin, W., G. K. Price, and J. Fernandez-Cornejo. "Estimating Farm-Level Effects of Adopting Herbicide-Tolerant Soybeans," *Oil Crops Situation and Outlook Yearbook*, OCS-2001, U.S. Dept. Agr., Econ. Res. Serv., October 2001.

Lin, W., P. C. Westcott, R. Skinner, S. Sanford, and D. G. De La Torre Ugarte. S*upply Response Under the 1996 Farm Act and Implications for the U.S. Field Crops Sector*, TB-1888, U.S. Dept. Agr., Econ. Res. Serv., July 2000.

Marra, M., G. Carlson, and B. Hubbell. "Economic Impacts of the First Crop Biotechnologies." North Carolina Agr. Res. Service, North Carolina State University, Raleigh NC. 1996. *www.ag-econ.ncsu.edu:8250/faculty/marra/FirstCrop/sld001.htm*

McBride, W. D. "Using Cost and Return Data in Estimating Benefits from Biotechnology Adoption." Presented at the American Agricultural Economics Association meeting, Tampa, FL, July 30-August 2, 2000.

Meyer, L. A. "An Economic Analysis of U.S. Total Fiber Demand and Cotton Mill Demand," *Cotton and Wool Situation and Outlook Yearbook*, CWS-1999, November 1999.

Moschini, G., and H. Lapan. "Intellectual Property Rights and the Welfare Effects on Agricultural R&D," *American Journal of Agricultural Economics* 79:1229-1242, 1997.

Moschini, G., H. Lapan, and A. Sobolevsky. "Roundup Ready® Soybeans and Welfare Effects in the Soybean Complex," *Agribusiness* 16(2000): 33-55.

Mullins, J. W., and J. M. Mills. "Economics of Bollgard Versus Non-Bollgard Cotton in 1998," *Proceedings of the Beltwide Cotton Conferences*, vol. 2, P. Dugger and D. Richter, eds., Memphis, TN: National Cotton Council of America, 1999.

Paarlberg, R. "The Global Food Fight," *Foreign Affairs* 79(2000): 24-38.

Pinstrup-Andersen, P., N. Ruiz de Londoño, and E. Hoover. "The Impact of Increasing Food Supply on Human Nutrition: Implications for Commodity Priorities in Agricultural Research and Policy," *American Journal of Agricultural Economics* 58(1976): 131-142.

Plexus Marketing Group, Inc., and Timber Mill Research, Inc. Enhanced Market Data Cotton 1997/1998 Report. Indianapolis, IN: Timber Mill Research, Inc, 1997.

Rawlinson, J., and A. Martin. "Weed Management Strategies in Soybeans." Unpublished manuscript. Cooperative Extension, University of Nebraska, November 10, 1998.

ReJesus, R. M., J. K. Greene, M.D. Hamming, and C.E. Curtis. "Economic Analysis of Insect Management Strategies for Transgenic Bt Cotton Production in South Carolina." *Proceedings of the Beltwide Cotton Conference*, vol. 1, P. Dugger and D. Richter, eds. Memphis, TN: National Cotton Council of America, 1997.

Smith, K., N. Ballenger, K. Day-Rubenstein, P. Heisey, and K. Klotz-Ingram. "Biotechnology Research: Weighing the Options for a New Public-Private Balance," *Agricultural Outlook* AGO-265, October 1999.

Smith, K., and R. Heimlich. "Impacts of Adopting Genetically Engineered Crops in the U.S.: Preliminary Results." U.S. Dept. Agr., Econ. Res. Serv., July 1999.

Stark, C. R., Jr. "Economics of Transgenic Cotton: Some Indicators Based on Georgia Producers," *Proceedings of the Beltwide Cotton Conference*, vol. 1, P. Dugger and D. Richter, eds. Memphis, TN: National Cotton Council of America, 1997.

Sullivan, J., J. Wainio, and V. Roningen. A Database for Trade Liberalization Studies. ERS Staff Report No. 89-12, U.S. Dept. Agr., Econ. Res. Serv., 1989.

U.S. Department of Agriculture, National Agricultural Statistics Service. *Agricultural Chemical Usage: 1997 Field Crops Summary*. Ag Ch 1(98), May 1998a.

_____, National Agricultural Statistics Service. *Crop Production: 1997 Summary*. Cr Pr 2-1(98), January 1998b.

_____, National Agricultural Statistics Service. *Agricultural Prices: 1997 Summary*. Pr 1-3(98), July 1998c.

_____, National Agricultural Statistics Service. *Prospective Plantings*. Cr Pr 2-4 (3-00), March 2000a.

_____, Economic Research Service. *Oil Crops Situation and Outlook Yearbook*. OCS-2000, October 2000b.

_____, Office of the Chief Economist. *World Agricultural Supply and Demand Estimates*. WASDE-358, January 2000c.

_____, National Agricultural Statistics Service. *Prospective Plantings*. Cr Pr 2-4 (3-01), March 2001a.

_____, National Agricultural Statistics Service. *Acreage*. Cr Pr 2-5 (6-01), June 2001b.

_____, Economic Research Service. *Cotton and Wool Situation and Outlook Yearbook*. CWS-2001, November 2001c.

_____, National Agricultural Statistics Service. *Acreage*. Cr Pr 2-5 (6-02), June 2002.

_____, National Agricultural Statistics Service. *Acreage*. Cr Pr 2-5 (6-03), June 2003.

U.S. Environmental Protection Agency. "*Bacillus thuringiensis* Plant-Pesticides." Biopesticides Registration Action Document: Preliminary Risks and Assessments Sections, 2000.

Uri, N. D., G. V. Chomo, B. Hyberg, and R. Hoskin. "The Price Elasticity of Export Demand for Soybeans and Soybean Products Reconsidered," *Oxford Agrarian Studies* 22(1994): 41-63.

Virginia Cooperative Extension. "Boll Drop Problems in Roundup-Resistant Cotton." *www.filebox.vt.edu/cals/cses/chagedor/bolldrp.html*, 2001.

Williams, M. W. "Cotton Insect Losses 1996." *Proceedings of the Beltwide Cotton Conference*, vol. 2, P. Dugger and D. Richter, eds. Memphis, TN: National Cotton Council of America, 1997.

Appendix A: Empirical Model for Measuring the Changes in Economic Surpluses

The empirical economic surplus model proposed by Alston et al. is based on the assumption that the U.S. and ROW supply and demand functions can be modeled with the following equations:

U.S. supply: $Q_{US} = \alpha_{US} + \beta_{US} (P + k_{US}) = (\alpha_{US} + \beta_{US} k_{US}) + \beta_{US} P$,

U.S. demand: $C_{US} = \gamma_{US} - \delta_{US} P$,

ROW supply: $Q_{ROW} = \alpha_{ROW} + \beta_{ROW} (P + k_{ROW}) = (\alpha_{ROW} + \beta_{ROW} k_{ROW}) + \beta_{ROW} P$,

and

ROW demand: $C_{ROW} = \gamma_{ROW} - \delta_{ROW} P$,

where Q_{US} and C_{US} are the quantities produced and consumed of the commodity (which may include biotech and/or conventional varieties) in the United States. Similarly, Q_{ROW} and C_{ROW} are the quantities produced and consumed in the ROW.[1] The terms k_{US} and k_{ROW} are the vertical shift in the U.S. and ROW supply curves due to the introduction of biotechnology. Last, P is the equilibrium world price of the commodity. A graphical representation of this model is presented in figure 5.

The first step in deriving the formulas that determine changes in producer and consumer surpluses is to use the identity $Q_{US} + Q_{ROW} = C_{US} + C_{ROW}$, which allows for the estimation of P. The existence of a single equilibrium world price follows from the Law of One Price assumption, which states that regional prices only differ from the world price by transportation costs (Falck-Zepeda et al., 2000a).

The equilibrium price observed after the introduction of biotechnology is referred to as P_1, while the counterfactual price—the price that would have prevailed had the technology not been introduced and identical supply and demand conditions existed—is denoted by P_0. Because the welfare changes associated with the adoption of biotechnology are measured relative to the absence of the innovation, P_0 must be estimated. The formula for estimating the world price is

$$P = (\gamma_{US} + \gamma_{ROW} - \alpha_{US} - \alpha_{ROW} - \beta_{US} k_{WORLD}) / (\beta_{US} + \delta_{US} + \beta_{ROW} + \delta_{ROW}),$$

where k_{WORLD} is the sum of k_{US} and k_{ROW}. If there is no supply shift, k_{US}, k_{ROW}, and thus k_{WORLD}, equal 0 and

$$P = P_0 = (\gamma_{US} + \gamma_{ROW} - \alpha_{US} - \alpha_{ROW}) / (\beta_{US} + \delta_{US} + \beta_{ROW} + \delta_{ROW}).$$

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[1] As in the Moschini and Lapan model, this study does not consider consumer heterogeneity in valuing biotech innovations. Different consumer preferences toward biotech products and government regulations among export markets could lead to divergent values of biotech and nonbiotech products for U.S. and ROW consumers. Considering consumer heterogeneity could affect the resulting surplus changes, including the benefits for consumers as a whole as well as those with divergent preferences toward biotech products, in this study.

On the other hand, if there is a shift in supply due to the introduction of biotechnology and k_{WORLD} equals KP_0, where $K = k_{WORLD}/P_0$, then $P = P_1 = (\gamma_{US} + \gamma_{ROW} - \alpha_{US} - \alpha_{ROW} - \beta_{US} K P_0) / (\beta_{US} + \delta_{US} + \beta_{ROW} + \delta_{ROW})$ and the change in price, $P_1 - P_0 = - \beta_{US} KP_0 / (\beta_{US} + \delta_{US} + \beta_{ROW} + \delta_{ROW})$. The absolute value of the relative price change (Z) is $Z = -(P_1 - P_0) / P_0 = \beta_{US} K / (\beta_{US} + \delta_{US} + \beta_{ROW} + \delta_{ROW})$, which is assumed to be the same for all U.S. production regions due to the Law of One Price. By using the trade equilibrium assumption $QT_0 = C_{ROW,0} - Q_{ROW,0} = Q_{US,0} - C_{US,0}$ (the zero subscripts indicate counterfactual values), Z can be defined in elasticity form as

$$Z = \varepsilon_{US} K / [\varepsilon_{US} + S_{US} \eta_{US} + (1 - S_{US}) \eta_{EROW}].$$

The term ε_{US} is the U.S. supply elasticity for the biotech crop, η_{US} is the absolute value of the U.S. demand elasticity for the commodity, η_{EROW} is the absolute value of the net export demand elasticity, and S_{US} is the share of U.S. production that is consumed domestically.

As adapted from Alston et al., the formulas for changes in producer and consumer surpluses in the United States and the ROW are:

$$\Delta PS_{US} = P_0 Q_{US,0} (K_{US} - Z) (1 + 0.5 Z\varepsilon_{US}),$$

$$\Delta CS_{US} = P_0 C_{US,0} Z (1 + 0.5 Z \eta_{US}),$$

$$\Delta PS_{ROW} = -P_0 Q_{ROW,0} (K_{ROW} - Z) (1 + 0.5 Z\varepsilon_{ROW}),$$

$$\Delta CS_{ROW} = P_0 C_{ROW,0} Z (1 + 0.5 Z \eta_{ROW}),$$

$$\Delta USAS_{US} = \Delta CS_{US} + \Delta PS_{US},$$

and

$$\Delta ROWS_{ROW} = \Delta CS_{ROW} + \Delta PS_{ROW},$$

where ΔPS_{US} is the change in U.S. producer surplus, ΔCS_{US} is the change in U.S. consumer surplus, ΔPS_{ROW} is the change in ROW producer surplus, ΔCS_{ROW} is the change in ROW consumer surplus, ε_{ROW} is the ROW supply elasticity, and η_{ROW} is the absolute value of the ROW demand elasticity. The terms $\Delta USAS_{US}$ and $\Delta ROWS_{ROW}$ represent the change in total surplus in the United States and ROW. These formulas assume that the pre-adoption world and U.S. regional prices, quantities, and relevant elasticities are known. While the counterfactual commodity prices and quantities are not known, they can be estimated from the equations above. Following Alston et al. and Pinstrup-Andersen et al., the equations are:

$$P_0 = P_1 / \{1 - [\varepsilon_{US} K / [\varepsilon_{US} + S_{US} \eta_{US} + (1 - S_{US})\eta_{EROW}] \}$$

and

$$Q_0 = Q_1 / \{1 + [\varepsilon_{US} K ((S_{US} \eta_{US}) + (1 - S_{US})\eta_{EROW})] / [\varepsilon_{US} + S_{US} \eta_{US} + (1 - S_{US}) \eta_{EROW}]\}.$$

After estimating the shift in supply due to the adoption of biotechnology as well as the counterfactual world price, the surplus changes accruing to U.S. farmers, U.S. consumers, and ROW consumers and producers are calculated. The gains realized by the technology innovators are estimated separately using data on adoption rates, technology fees, and seed premiums.

Appendix B: Differences in Estimated Surplus Changes for Herbicide-Tolerant Soybeans Due to Different Analytical Frameworks

This section attempts to reconcile differences in the estimates of surplus changes resulting from two separate analytical frameworks. This study relies on an approach used by Falck-Zepeda et al. (2000a) to estimate the size and distribution of benefits resulting from the adoption of biotech crops. Two key characteristics of their framework are (1) linear supply and demand functions, and (2) parallel shifts in supply. In contrast, the model developed by Moschini et al. allows for a nonlinear specification of the supply and demand curves and nonparallel shifts in supply. These two approaches are chosen for reconciliation here since both address the size and distribution of benefits resulting from the adoption of herbicide-tolerant soybeans. While herbicide-tolerant soybeans are highlighted in this example, the general conclusions would likely be applicable to other commodities.

Differences in the findings arising from these two approaches may be attributed to several factors, including key features of the frameworks, supply and demand elasticity assumptions, and the farm-level effects. To assess the effect of these two frameworks on estimated surplus changes, differences in other factors must be controlled. To do this, assumptions concerning supply and demand elasticities and farm-level effects were equalized across the two frameworks. That is, the assumptions made by Falck-Zepeda et al. (2000a) were replaced by those in the Moschini et al. study.

To reconcile these two different approaches, the following key parameters in this study's framework were altered:

(a) Elasticities of supply were changed to 0.8 for both the United States and ROW. Because Moschini et al. specify a three-market model, South America and the ROW were combined into one ROW region to conform with the two-market model in Falck-Zepeda et al. (2000a). The 0.8 supply elasticity for the combined ROW region is an average of the elasticities for the ROW (0.6) and South America (1.0) in Moschini et al.

(b) Herbicide cost savings was changed to $20 per hectare.

(c) Yield advantage was eliminated.

(d) Soybean demand elasticity was lowered to –0.4.

(e) Per-hectare seed cost was changed to $45 for the United States and $40 for the ROW.

(f) Herbicide-tolerant seed costs were adjusted to be 43 percent and 22 percent higher than that for conventional seed in the United States and the ROW, respectively, to reflect the technology fees paid by adopters.

Altering the supply and demand elasticity assumptions and farm-level effects to conform with those used in Moschini et al. leads to similar changes in the estimated stakeholder welfare, except for ROW producer surplus (appendix table B-1). Using the Falck-Zepeda et al. (2000a) framework, U.S. producers captured nearly 20 percent of the estimated surplus gain created by the adoption of the herbicide-tolerant soybeans. In both cases, innovators' profits account for approximately half of the estimated total world benefit. However, in the case of ROW farmers, the re-estimation of the model renders an estimated welfare loss of about $112 million—significantly higher than the estimated $31-million loss based on the Moschini et al. framework. Although equalizing many of the assumptions largely reconciles the differences between the two approaches, specification of the model structure appears to account for the remaining discrepancies between the two sets of results.

Appendix table B-1—Comparison of analytical frameworks for herbicide-tolerant soybeans

Stakeholder	Surplus gain in this study[1]		Surplus gain from Moschini et al.[2]	
	$ million	*% of total*	*$ million*	*% of total*
U.S. producers	135.2	19	156.0	19
U.S. consumers	93.0	13	81.0	10
Innovators	368.8	51	358.0	45
ROW producers	-112.1		-31.0	
ROW consumers	227.7		237.0	
Net ROW	115.7	16	206.0	26
World benefit	702.7		804.0	

[1] Incorporates the assumptions described above in this appendix so as to reflect those made by Moschini et al. However, the framework is the same as the one used in this study to generate estimated surplus gains for the various stakeholders.

[2] Reported in Moschini et al., who use a different framework from the one used in this study.