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.

[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 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

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]

[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.

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-

Figure 7

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

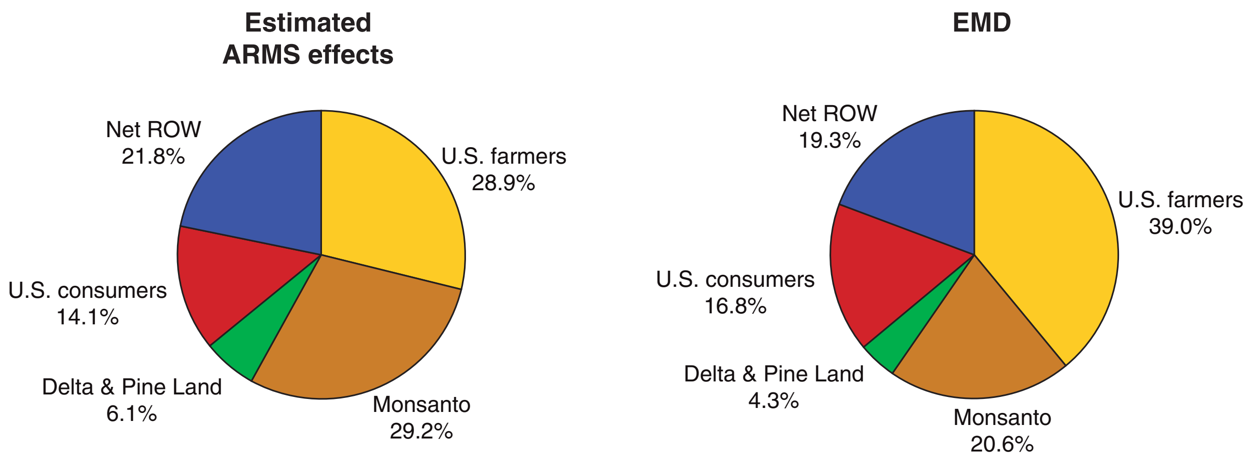
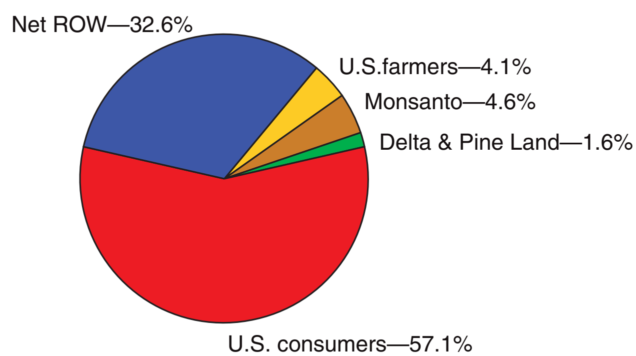


Table 11—Estimates of surplus changes for herbicide-tolerant cotton, 1997

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.

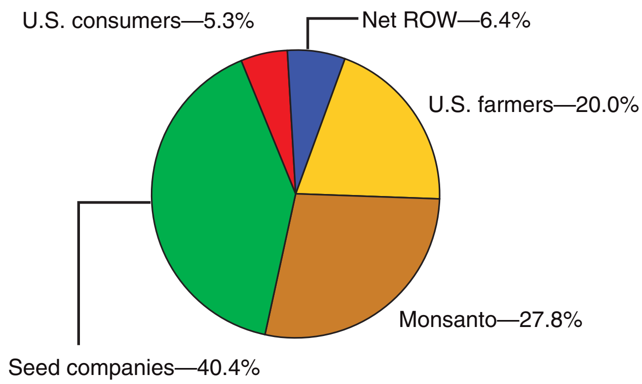
U.S. consumers benefited through increased soybean supply, which lowered the world price by 1.2 cents per bushel (0.17 percent of the counterfactual world price of $7.06 per bushel). Domestic consumers received only 5 percent of the estimated total benefit from herbicide-tolerant soybeans (fig. 9). Because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



[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.

[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).

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 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).