# The Distribution of Benefits Resulting from Biotechnology Adoption

by

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Presented at

American Agricultural Economics Association Annual Meeting
Chicago, Illinois
August 5-8, 2001

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## Introduction

The adoption of agricultural biotechnology has grown rapidly in recent years, partly due to advantages reaped by producers. These benefits include potential crop yield increases, pest control cost savings, and/or ease of management. Despite the benefits to producers that have been attributed to biotechnology, concerns have been raised as to whether biotech and seed companies might have captured the majority of the benefits and whether fairness to farmers has been maintained. Concerns over the distributional effect of biotech adoption carry policy significance at the national level.

The purposes of this study are two-fold: (1) to estimate the size of total benefits arising from the adoption of agricultural biotechnology, and (2) to measure the distribution of total benefits among key stakeholders along the marketing chain, including U.S. farmers, gene developers, germplasm suppliers, U.S. consumers, and the producers and consumers in the rest of the world (ROW). This study focuses on the benefits that resulted from the adoption of herbicide-tolerant soybeans as well as Bt and herbicide-tolerant cotton in 1997, the last year for which complete data from the USDA's Agricultural Resource Management Study (ARMS) survey are available. In this study, various data sources are examined for measuring the farm-level effects of adopting biotechnology and the resulting benefit estimates are compared. In addition, we use recent estimates of supply and demand elasticities that are consistent with the current policy and market environment. Finally, this study makes use of information from distribution surveys at the regional level, which more realistically reflects actual commodity flows from specific production regions to export markets.

## Previous Related Studies

A few studies have addressed the distribution of benefits from adopting Bt cotton and herbicide-tolerant soybeans [e.g., Falck-Zepeda, Traxler, and Nelson$_a$ (FZ$_a$); FZ$_b$; Frisvold, Tronstad, and Mortensen (FTM); Moschini, Lapan, and Sobolevsky (MLS)]. These analyses consider the economic benefits accruing to U.S. farmers, U.S. consumers, the technology innovators, seed companies, and the consumers and producers in the ROW. Most of these studies rely on a specific data source for measuring biotechnology's impacts on crop yields and pest control costs without paying attention to alternate data sources that might yield more plausible results. In addition, it is known that the total benefit and its distribution hinge on the supply and demand elasticity assumptions in the domestic and world markets. Yet previous studies rely on a wide range of elasticity estimates, which are out-of-date and inconsistent with the current policy and market environment. Furthermore, these studies do not making use of survey data on the distribution of biotech crops at the regional level. The following two sections review key past studies that have estimated the distribution of benefits from Bt cotton and herbicide-tolerant soybeans.

### *Studies of Bt Cotton*

FZ$_a$ estimated the distribution of benefits arising from the adoption of Bt cotton in the U.S. in 1997. The authors adopted a theoretical framework developed by Moschini and Lapan (ML) for assessing the welfare impacts of an innovation where the innovator behaves as a monopolist under the protection of intellectual property rights (IPR). The change in social welfare was measured in both the input and output markets, and encompassed the change in Marshallian surplus and the monopoly profit captured by the innovator. The introduction of the technology was modeled in a large open economy with technological spillovers. The authors assumed perfect technology transfer; that is, producers in the ROW obtain the same yield gains and reductions in insect control costs as U.S. farmers. Regional data were employed to account for differences in adoption rates, yield increases, and reductions in insecticide costs due to the technology. Farm-level impacts in the Southeast and Delta were taken from EMD data (Plexis Marketing Group, Inc, and Timber Mill Research, Inc.), which compared like plots, thus partially isolating the impacts of the technology. Data for other regions were obtained from Monsanto and Delta & Pine Land. The gain or reduction in the stakeholders' welfare depends critically on the regional adoption rates, technology fees and seed premiums, farm-level effects, and elasticities of supply and demand (table 1). $FZ_a$ results are provided in table 2.

The results of $FZ_a$'s study are subject to qualifications based on a number of important assumptions in their model. First, while the use of the EMD data eliminated some of the extraneous effects on yields and pest control cost savings on fields in the Delta and Southeast, the authors did not isolate the farm-level impacts in other regions. Reported yields and pest control cost savings that are larger than their actual values may exaggerate the benefits received by U.S. and ROW producers. Second, the supply and demand elasticities assumed in their studies are outdated and do not properly reflect producers' responses price changes under current farm policy and market conditions. For example, the supply elasticity assumed in their analysis (0.86) is nearly double the 0.466 national supply elasticity estimated by Lin *et al*. Third, $FZ_a$ assumed that each region in the U.S. exports the same share of cotton that is produced. In fact, the shares of cotton that are consumed domestically and exported to the ROW vary considerably across regions. Fourth, it was assumed that the proportion of U.S. cotton production exported to

Table 1. Comparison of Supply and Demand Elasticity Assumptions

| | **This study** | **Falck-Zepeda et al.** | **Frisvold et al.** |
|---|---|---|---|
| *Stakeholder* | *1997 Bt Cotton*<br>*1997 HT Cotton* | *1997 Bt Cotton* | |
| U.S. Supply Elasticity | 0.466 | 0.84 | 0.0 |
| U.S. Demand Elasticity | -0.494 | -0.101 | -0.3 |
| Net Export Demand | -2.34 | -1.62 | -2.0 |
| ROW Supply Elasticity | 0.15 | 0.15 | n.a. |
| ROW Demand Elasticity | -0.13 | -0.13 | n.a. |

| | **This study** | **Falck-Zepeda et al.** | **Moschini et al.** |
|---|---|---|---|
| | | *1997 HT Soybeans* | |
| U.S. Supply Elasticity | 0.269 | 0.22 and 0.92 | 0.8 |
| U.S. Demand Elasticity | -0.5 | -0.42 | -0.4 |
| Net Export Demand | -1.21 | -0.614 | n.a. |
| ROW Supply Elasticity | 0.3 | 0.3 | 0.6 |
| ROW Demand Elasticity | -0.07 | -0.07 | -0.4 |
| S.A. Supply Elasticity | n.a. | n.a. | 0.1 |
| S.A. Demand Elasticity | n.a. | n.a. | -0.4 |

n.a.= not applicable.

Table 2--Results from previous analyses on the distribution of benefits

| | **1997 Bt Cotton** | | | | **1997 Herbicide-Tolerant Soybeans** | | | |
|---|---|---|---|---|---|---|---|---|
| *Stakeholder* | *Falck-Zededa et al.* | | *Frisvold et al.** | | *Falck-Zepeda et al.*[$] | | *Moschini et al.*[&] | |
| | *mil. $* | *%* | *mil. $* | *%* | *mil. $* | *%* | *mil. $* | *%* |
| U.S. Farmer Surplus | 80.0 | 42 | 7.2 | 5 | 808.3 | 76 | 156 | 19 |
| U.S. Consumer Surplus | 14.0 | 7 | 45.2 | 29 | 44.5 | 4 | 82 | 10 |
| Monsanto | 67.1 | 35 | 73.4 | 47 | 78.0 | 7 | 358.0 | 45 |
| Delta and Pine Land | 17.7 | 9 | n.a. | | n.a. | | n.a. | |
| Seed Companies | n.a. | | n.a. | | 31.9 | 3 | n.a. | |
| ROW Producer Surplus | -12.1 | | 308 | | 30.6 | | -31.0 | |
| ROW Consumer Surplus | 23.4 | | 339.4 | | 68.4 | | 239.0 | |
| Net ROW | 11.3 | 6 | 31.4 | 20 | 99 | 9 | 208.0 | 26 |
| Total World Surplus | 190.1 | | 157.2 | | 1061.7 | | 804.0 | |

n.a. = not applicable.

* Results are for moderate impacts on crop yields and insect control costs. U.S. farmer benefits exclude government payments. The surplus gain for Monsanto includes the benefits for the seed companies.

[$] Reported results are based on a U.S. supply elasticity of 0.22.

[&] The surplus gain for Monsanto includes the benefits for the seed companies. The welfare gain for the ROW includes the gain accrued to South America.

the ROW is the same as the proportion of imports in ROW cotton production. The assumption that the ROW is a mirror image of the U.S. is inaccurate.

FTM developed a mathematical model based on regional data to estimate the distribution of benefits from adopting Bt cotton. The model separates adopter and non-adopter benefits and allows for government price support payments. Rather than assuming a particular shift in the supply curve, the authors specified the cotton supply as a step function to allow the regional impacts to shape the curve. [1] Adoption, yield, and cost of production data were taken from many of the same sources used by $FZ_b$, which do not isolate the farm-level impacts. The model's results were obtained by first solving a baseline model with either low, moderate, and high changes in yields and insect control costs and then comparing the findings with those of a constrained model where no Bt cotton was assumed to be planted. The results obtained with moderate impacts are given in table 2. FTM's findings differ considerably from those of $FZ_a$, particularly with respect to the benefits received by U.S. farmers and U.S. consumers. For example, FTM found that U.S. farmers obtained only 5 percent of the total world benefit, compared with 42 percent in $FZ_a$'s study.

### *Studies of Herbicide-tolerant Soybeans*

The benefits from adopting herbicide-tolerant soybeans in 1997 were estimated by $FZ_a$ using the same methodology applied to Bt cotton (table 2). Adopters' and nonadopters' mean yields and mean weed control costs were obtained from the ARMS survey. Because this data source does not isolate the farm-level effects of the technology, the benefits to producers and

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[1] A parallel shift in the cotton supply function was assumed $FZ_a$'s study.

consumers may be overstated. Many of the concens associated with $FZ_a$'s analysis of Bt cotton apply to their study of herbicide-tolerant soybeans.

MLS developed a three-region spatial equilibrium model (covering the U.S., South America, and the ROW) for the soybean complex to evaluate the welfare effects of herbicide-tolerant soybeans. The spatial model seeks to solve for the market equilibrium prices and quantities of soybeans and soybean products (soybean mean and soybean oil) under a base scenario (assuming biotech adoption) and an alternate scenario (without biotechnology) for 1999/2000. Differences in the prices and quantities between the two scenarios indicate the impact of biotechnology adoption. The model takes into account differences in supply and demand structures for soybeans and its products, but also for the new technology embedded in the herbicide-tolerant soybean seeds. The model's specification permits a non-linear supply function and a non-parallel shift in the supply curve induced by the introduction of the technology.

Adoption rates that were expected to represent actual plantings of herbicide-tolerant soybeans in 1999 were employed in their study. Like $FZ_a$, supply and demand elasticities were taken from existing models and vary from those used in this study (table 1). It was assumed that adopters in 1999 realized an average saving of \$20 per hectare in variable production costs. The results of MLS' model are provided in table 2.

## Theoretical Framework

The model used to estimate the distribution of benefits is derived from a theoretical framework developed by ML for assessing the welfare impacts of an innovation where the innovator behaves as a monopolist under the protection of IPR. The change in social welfare is measured in both the cotton lint or soybean (output) and seed (input) markets, and encompasses the change in Marshallian surplus and the monopoly profit captured by the innovator.

Economic surplus was measured by following several steps: (1) the technology-induced shift in each commodity's supply was estimated for several production regions using data on adoption rates, crop yields, and cost savings net of increased seed costs (i.e., technology fees and seed premiums); (2) the impacts of the new technology on world and regional prices were calculated; (3) the distribution of Marshallian surplus in the domestic and international markets was estimated using an approach developed by Alston, Norton, and Pardey (ANP); and (4) the monopoly profits accrued to the technology innovators were estimated.

The empirical estimation of the stakeholders' benefits allows research-induced Marshallian surplus generated in an output market to be partitioned between producers and consumers. The ANP approach is modified to accommodate surplus gains in the input market as suggested by ML. In this study, ANP's model for a large open-economy with technological spillovers was used for Bt cotton and herbicide-tolerant soybeans. No technological spillovers were assumed in the case of herbicide-tolerant cotton since it was grown only in the U.S. in 1997. Additionally, the law of one price was assumed for the U.S. and world markets.

The economic surplus model proposed by ANP is based on the assumption that the U.S. and the rest of the world (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 either cotton or soybeans in the U.S., respectively. Similarly, $Q_{ROW}$ is quantity of cotton or soybeans produced in the ROW, and $C_{ROW}$ is quantity consumed of either of those commodities in the ROW. The terms $k_{US}$ *and* $k_{ROW}$ are the vertical (price) shift in US and ROW supply curves due to the introduction of the new technologies, respectively. Lastly, P is the equilibrium world price of cotton or soybeans. A graphical representation on this model is presented in figure 1.

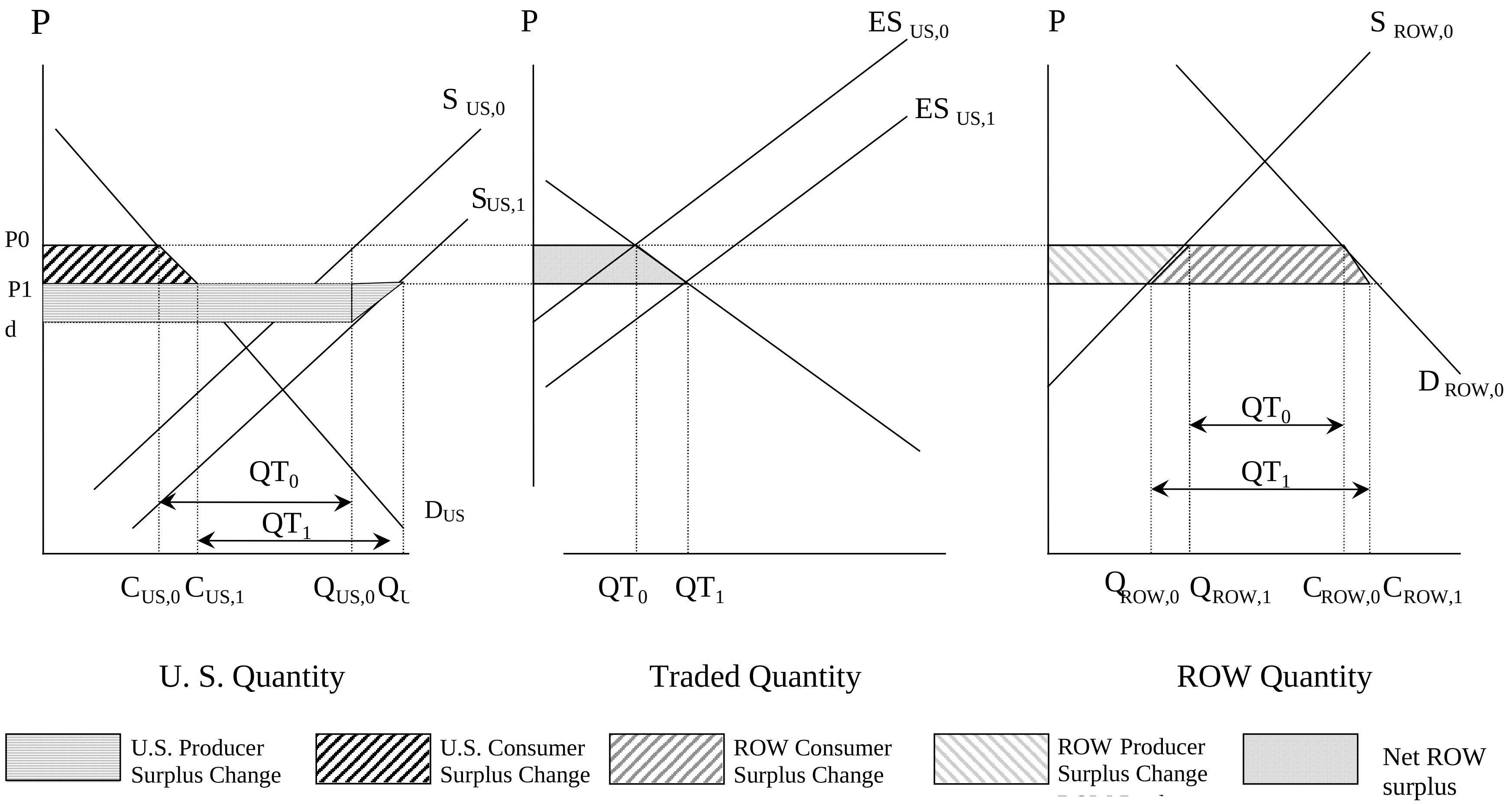
The first step in deriving the formulas that determine producer and consumer surpluses is to use the identity $Q_{US} + Q_{US} = C_{ROW} + C_{ROW}$, which allows the estimation of world price P by substitution and algebraic manipulation. The existence of a single equilibrium price follows from the Law of One Price assumption. Once a new technology is introduced and adopted, only the price that results from the supply shift can be observed, and this observed equilibrium price is referred to as $P_1$. It is not possible to observe the counterfactual price, $P_0$--the price that would have prevailed in 1997 if all supply and demand conditions were identical and the technology had not been introduced. Because the surplus measures are made relative to the absence of the innovation, $P_0$ must be estimated. The estimation of $P_0$ is based on the internal consistency and assumptions of the model. The formula for estimating the world price is

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

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

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

If there is a shift in the supply curve due to the introduction of a new technology and $k_{WORLD}$ equals $KP_0$, where $K = k_{WORLD}/P_0$, then $P = P_1 = (\gamma_{US} + \gamma_{ROW} - \delta_{US} - \delta_{ROW} - \beta_{US}\, K\, P_0) / (\beta_{US} + \gamma_{US} + \beta_{ROW} + \delta_{ROW})$ and the change in price $P_1 - P_{0,} = - \beta_{US}\, KP_0 / (\beta_{US} + \gamma_{US} + \beta_{ROW} + \delta_{ROW})$. The


P
S US,0
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CUS,0 CUS,1
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U. S. Quantity
P
ES US,0
ES US,1
QT0
QT1
Traded Quantity
P
S ROW,0
D ROW,0
QT0
QT1
QROW,0 QROW,1
CROW,0 CROW,1
ROW Quantity
U.S. Producer Surplus Change
U.S. Consumer Surplus Change
ROW Consumer Surplus Change
ROW Producer Surplus Change
Net ROW surplus

absolute value of the relative price change (Z) is Z= $(P_1 - P_0) / P_0 = \beta_{US} KP_0 / (\beta_{US} + \gamma_{US} + \beta_{ROW} + \delta_{ROW})$. 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:

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

where $\varepsilon_{US}$ is the U.S. supply elasticity for cotton lint or soybeans, $\eta_{US}$ is the absolute value of U.S. demand for either commodity, $\eta^{EB}$ is the absolute value of the net export demand elasticity, and $S_{US}$ is the share of U.S. cotton or soybean production that is consumed domestically. The formulas for producer and consumer surpluses in the U.S. and the ROW are:

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

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

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

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

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

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

where $\Delta CS_{US}$ is the change in consumer surplus in the U.S., $\Delta PS_{US}$ is the change in producer surplus in the U.S., $\Delta CS_{ROW}$ is change in consumer surplus in the ROW, and $\Delta PS_{ROW}$ is change in producer surplus in the ROW. The terms $\Delta USAS_{US}$ and $\Delta ROWS_{ROW}$ represent the changes in total surplus in the U.S. and ROW, respectively.

Counterfactual prices, quantities, and relevant elasticities may be estimated with the following formulas, which are derived from the system equations above:

$$P_0 = P_1 / \{1 - [\varepsilon_{US} K / [\varepsilon_{US} + S_{US} \eta_{US} + (1- S_{US}) \eta^{EB}] \} \text{ and}$$

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

## Data and Assumptions

Given that variations in farm-level impacts may significantly affect the distribution of benefits, the present study utilizes several data sources to obtain a range of surplus estimates. Information from the ARMS survey was used to determine stakeholder benefits in the cases of Bt cotton, herbicide-tolerant cotton, and herbicide-tolerant soybeans. This data source provided mean adoption rates and crop yields as well as mean seed, chemical, application, scouting, and cultivation costs for conventional and biotech varieties by ERS production region. One drawback of the mean ARMS data is that it incorporates other factors beyond the technology that may affect crop yields and pest control costs.

Elasticities that isolate the impact of biotech adoption on crop yields and pesticide use (Fernandez *et al*.) were used to replace the mean ARMS data, when appropriate. For example, using the elasticity-based estimates, Bt cotton farmers in the Southern Seaboard (roughly equivalent to the Southeast) realized a 21 percent yield increase over producers of traditional varieties in that region. The mean ARMS yield increase of 11.6 percent for that region was replaced with the 21-percent gain, and the mean ARMS yields were used for other regions since the elasticity-based estimate applied only to the Southern Seaboard. Moreover, all mean ARMS data on herbicide-tolerant soybean yields were replaced with the elasticity-adjusted estimates since they applied to all production regions.

A third source of yield and insect control cost data (Bt cotton only) was the EMD data, which applied only to producers in the Southern Seaboard and Mississippi Portal (Delta region). The EMD data are similar to the elasticity-based impacts in that they isolate the effect of the technology on crop yields and pest control costs. Because the data pertained only to producers in certain regions, the mean ARMS data on yields and production costs were used for all other cotton-producing areas.

Unlike $FZ_a$, this study assumes that the ROW achieved a technology transfer efficiency of 50 percent in the cases of Bt cotton and herbicide-tolerant soybeans. That is, ROW producers obtained half of the yield increases and savings in pest control costs that were realized by U.S. farmers in 1997. Since herbicide-tolerant cotton varieties were only available in the U.S. that year, the rate of technology transfer to the ROW was set at zero.

Crop production data by state were obtained from USDA's National Agricultural Statistics Service ($USDA\text{-}NASS_b$). Regional adoption data as well as seed prices, premiums, technology fees were taken from USDA's ARMS survey. Commodity prices were estimated by ERS crop production region using state price data ($USDA\text{-}NASS_a$) and weighting those values by the share of regional production attributed to that state. Herbicide and insecticide prices were obtained from Gianessi and Marcelli and $USDA\text{-}NASS_a$, with state-level data on pesticide application rates and the percentage of area treated with various chemicals being obtained from $NASS_c$.

In general, the estimation of the stakeholders' surpluses relied on $FZ_b$'s framework. However, a number of their assumptions were changed to more accurately reflect commodity flows and trade patterns. Realizing that some production regions may export greater percentages of their production than others, state-level shipment data from 1993/94 (Gale, Johnson, and Meyer) were used to estimate export-bound movements of cotton by production region in this study. Commodity flow patterns were also estimated for soybeans using a 1985 grain flow survey (Fruin, Halbach, and Hill)--the most recent information available. Another assumption that was modified in this study concerns the share of cotton imported by the ROW relative to its production. Data on ROW production and imports were taken from USDA's World Agricultural Supply and Demand Estimates (USDA-OCE) to calculate the share of ROW imports relative to ROW production.

The assumptions made in this study concerning U.S. and ROW supply and demand elasticites differ from those in previous analyses (table 1). In the cases of Bt cotton and hebicide-tolerant soybeans, $FZ_a$, FTM, and MLS relied on elasticity estimates that were previously reported in the literature. In this analysis, regional domestic supply elasticites were taken from a recent study by Lin *et al*. The values were preferred over those employed in the other studies because they are more up-to-date and reflect the current policy environment. The U.S. cotton mill demand elasticity was recently estimated by Meyer, and the net-export demand elasticity came from a recent study by Isengildina, Hudson, and Herndon. Like $FZ_a$, the ROW supply and demand elasticites were taken from a study by Sullivan, Wainio, and Roningen.

In this study, key variables, including crop yields, pest control costs, and supply and demand elasticities, were assigned probability distributions. Crop yields were assumed to have a normal distribution. In any given season, some producers experience below average yields while others achieve above-average yields. Most producers, however, typically have yields near the mean value. Seed, herbicide/pesticide, scouting, application, and cultivation costs were assumed to be log-normally distributed--a distribution that fits the mean ARMS data best. The standard errors for these distributions were obtained from the mean ARMS data. The U.S. demand elasticity for cotton was assigned a normal distribution since it was estimated with the two-stage least squares regression technique. The net-export demand elasticity was expected to have a triangular distriution, with –2.28 as the most likely value. $FZ_b$ also assigned probability distributions to key variables when estimating the distribution of benefits from the adoption of Bt cotton in 1996. However, distributions that roughly fit the values in the literature were used rather than those that are based on empirical data.

## Estimation Results

In order to obtain point estimates of the benefits realized by the stakeholders, a spreadsheet was developed to encompass the data on regional adoption rates, crop yields, seed costs, technology fees, pest control costs, commodity prices, and the supply and demand elasticities as well as the assumptions concerning commodity flows, export shares, and technology transfer. Formulas were used to calculate the estimated benefits. Then the model was simulated using the software package @Risk, allowing it to iterate until convergence.

### *Results for 1997 Bt Cotton*

When the mean ARMS data were employed exclusively, the benefits from adopting Bt cotton in 1997 totaled $140.2 million (table 3), with the U.S. capturing 83 percent of the world benefits. The total surplus increased with the elasticity-based estimates because of a higher yield effect and a greater pest control cost savings in the Southeast. The highest surplus estimate was obtained with the EMD data, primarily due to substantial savings in pest control costs. With the mean ARMS data and elasticity-based estimates, the size of the total world benefit and its division between the U.S. and the ROW are similar to that found by $FZ_a$ and FTM.

The value of the benefits received by U.S. farmers in 1997 resulting from Bt cotton adoption ranged from $31.4 million to $132.1 million (table 3). $FZ_a$’s estimate falls in the middle of this range, while that of FTM is significantly lower. The disparity in this study’s findings is due to the different assumptions concerning the extent of the technology’s impacts on

Table 3--Surplus Estimates for Bt Cotton

| | **Mean of ARMS** | | **Elasticity-based** | | **EMD** | |
|---|---|---|---|---|---|---|
| *Stakeholder* | *mil. $* | *%* | *mil. $* | *%* | *mil. $* | *%* |
| U.S. Farmer Surplus | 31.4 | 22.4 | 78.2 | 36.2 | 132.1 | 46.4 |
| U.S. Consumer Surplus | 9.9 | 7.1 | 19.9 | 9.2 | 30.9 | 10.8 |
| Monsanto | 62.0 | 44.2 | 62.0 | 28.7 | 62.0 | 21.8 |
| Delta & Pine Land | 12.9 | 9.2 | 12.9 | 6.0 | 12.9 | 4.5 |
| ROW Producer Surplus | -35.8 | | -77.8 | | -132.3 | |
| ROW Consumer Surplus | 59.8 | | 120.7 | | 179.3 | |
| Net ROW | 24.0 | 17.1 | 42.9 | 19.9 | 47.0 | 16.5 |
| | | | | | | |
| Total World Surplus | 140.2 | | 215.9 | | 284.9 | |

crop yields and pest control costs. The elasticity-based estimates' $46.8 million increase over the results obtained with the mean ARMS data is due primarily to the significantly higher yield impact in the Southern Seaboard. The difference between U.S. farmers' benefits with the mean ARMS and EMD data was due to the latter's significantly higher savings in pest control costs in the Southern Seaboard and Mississippi Portal. According to the EMD data, adopters pest control costs were 60 percent less that those of non-adopters in the two regions. The share of the total benefits accrued to U.S. farmers ranged from 23 to 46 percent, with the upper bound being in line with $FZ_a$.

The dollar value of the benefits realized by the innovators of the technology (Monsanto and Delta & Pine Land) remains constant across the three data sources due to the fixed Bt cotton acreage in 1997. Monsanto's benefit was determined primarily by the $32-per-acre technology fee that the company charged U.S. adopters.[2] In addition to a $7.11-per-acre royalty payment from Monsanto for the use of its parent genes ($FZ_b$), Delta & Pine Land derived a portion of its surplus from a $2-per-acre seed premium charged to U.S. farmers.[3] The share of the benefits realized by Monsanto was heavily dependent on the technology's impacts on crop yields and pest

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[2] Monsanto also collected the same technology fee in Mexico (37,100 acres) and $74 per acre in Australia (165,000).

[3] There was no seed premium was charged in other countries in 1997.

control costs. As the farm-level impacts increased, the majority share of the benefits shifted from Monsanto to U.S. farmers. The innovators' share of the benefits achieved with the mean ARMS data is consistent with that reported in previous studies.

Like $FZ_a$, U.S. consumers received a small portion of the total benefits--about 9 percent. The gain realized by U.S. consumers was the result of a larger cotton supply and a lower commodity price after the adoption of the technology (between 0.13 cents per pound and 0.53 cents per pound). The relatively small magnitude of the U.S. consumers' benefits is justifiable given the fact that the pest-resistant quality of Bt cotton is an input trait. This characteristic is appealing to producers because it reduces crop losses and lowers pest control costs. Beyond the reduction in price, consumers do not experience a direct benefit from the technology (such as health improvement).

Consumers and producers in the ROW realized a net benefit of $24.0 million to $47.1 million, depending on the data source (table 3). ROW consumers benefited from the adoption of Bt cotton because the increase in the cotton supply due to the new technology lowered the world price. Producers in other countries were hurt by the adoption of the technology. In 1997, the number of Bt cotton acres in the ROW was minimal. Since the majority of cotton producers grew traditional varieties, they did not realize the cost savings associated with Bt cotton and were fully exposed to the reduced world price.

### ***Results for 1997 Herbicide-Tolerant Cotton***

The size and distribution of benefits associated with the adoption of herbicide-tolerant cotton were estimated with the mean ARMS data and the elasticity-adjusted farm-level impacts. A net loss ($41.6 million) resulted with the mean ARMS data because herbicide-tolerant cotton yields were generally the same or lower than those of conventional varieties. These yields, combined with seed premiums and per-acre technology fees, more than outweighed the savings in weed control costs provided by the technology. As a result, U.S. producers realized a loss. Since the cotton supply was smaller with biotechnology, the world price increased, thus hurting U.S. and ROW consumers, but benefiting ROW producers.

The surplus estimates determined with the elasticity-based farm-level impacts conform more to a priori expectations than those computed with the mean ARMS data. With this data source, a positive surplus change ($231.6 million) was achieved, with the U.S. realizing the majority of the benefits (table 4). U.S. farmers gained $9.6 million from the adoption of herbicide-tolerant cotton due mainly to a 17-percent increase in adopters' yields. The higher yields, combined with savings in weed control costs, outweighed higher seed costs (including seed premiums and technology fees). U.S. farmers' share of the total benefits was small--about 4 percent--because their gains were overshadowed by the increase in surplus for U.S. consumers.

U.S. consumers benefited the most from the introduction of herbicide-tolerant cotton, gaining $132.2 million due to a lower cotton price. The larger supply caused the world price of cotton to fall by 2.5 cents per pound. According to table 4, the innovators captured about 7 percent of the surplus gain. On a net basis, the ROW gained $75.2 million, or 32 percent of the total world surplus gain.

## Results for Herbicide-Tolerant Soybeans

The gain in total world surplus from the adoption of herbicide-tolerant soybeans in 1997 ranged from $307.5 million to more than $1 billion (table 5). The upper range of the benefit

Table 4. Surplus Estimates for Herbicide-Tolerant Cotton

| | ARMS | Elasticity-based | |
|---|---|---|---|
| *Stakeholder* | *mil.$* | *mil.$* | *%* |
| U.S. Farmer Surplus | -6.5 | 9.6 | 4.1 |
| U.S. Consumer Surplus | -31.4 | 132.2 | 57.1 |
| Monsanto | 10.7 | 10.7 | 4.6 |
| Delta & Pine Land | 3.9 | 3.9 | 1.7 |
| ROW Producer Surplus | 177.5 | -733.3 | |
| ROW Consumer Surplus | -195.8 | 808.5 | |
| Net ROW | -18.3 | 75.2 | 32.5 |
| Total World Surplus | -41.6 | 231.6 | |

Table 5. Surplus Estimates for Herbicide-Tolerant Soybeans

| | ARMS | | Elasticity-based | |
|---|---|---|---|---|
| *Stakeholder* | *mil. $* | *%* | *mil. $* | *%* |
| U.S. Farmer Surplus | 455.7 | 44.2 | 61.9 | 20.1 |
| U.S. Consumer Surplus | 134.3 | 13.0 | 15.9 | 5.2 |
| Monsanto | 85.6 | 8.3 | 85.6 | 27.8 |
| Seed Companies | 124 | 12.0 | 124.6 | 40.5 |
| ROW Producer Surplus | -224.1 | | -34.2 | |
| ROW Consumer Surplus | 455.6 | | 53.7 | |
| Net ROW | 231.5 | 22.5 | 19.5 | 6.3 |
| Total World Surplus | 1031.1 | | 307.5 | |

estimates is comparable with the findings of $FZ_a$ and MLS. With the EMD data, the U.S. captured the lion's share of benefits at 94 percent.

When the impacts on yields and weed control costs from the mean ARMS data were employed, U.S. farmers were estimated to have received $455.7 million. However, with the elasticity-based impacts, farmers gained only $61.9 million. The large discrepancy in the benefit estimates was due to the mean ARMS data's significantly higher yields and pest control cost savings in a number of important soybean-producing regions. For example, the ARMS survey revealed that adopters of herbicide-tolerant soybeans in the Heartland region -- where 64 percent of U.S. soybeans were grown -- realized yields that were 14.2 higher and weed control costs that were 31 percent lower than those of non-adopters in 1997. The benefits for U.S. farmers obtained with the elasticity-based estimates are more justifiable because the yield impact is more in line with analysts' belief that the yield differences in 1997 were minimal, if not negative (Carpenter and Gianessi). While the value of U.S. farmers' benefit is in line with that by $FZ_a$, the share of the total surplus gain matches MLS' results.

The estimated benefit received by Monsanto (the developer of the technology), was the result of a \$7.25-per-acre technology fee that was charged to adopters.[4] The total benefit received by seed companies was derived from seed premiums that ranged from \$1.58 to \$8.47 per acre.[5] The benefits captured by Monsanto and the seed companies do not take into account 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 one lump sum of money. Other firms were required to pay annual licensing fees. Because the "use-of-technology" payment varied from firm to firm, it was not included in the calculation of the innovators' benefits.

The shares of the total benefits held by the innovators (Monsanto and the seed companies) in 1997 were relatively small when the ARMS farm-level impacts were used. These percentages rose considerably when the elasticity-based estimates of the farm-level impacts were used. The companies' portion of the benefits soared because U.S. farmers' surplus declined as a result of smaller yield impacts and weed control cost savings, thus allowing the firms' fixed

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[4] 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.

[5] The difference between the two surplus gains (table 5) occurs because the seed premiums were estimated by subtracting the traditional soybean price and the technology fee from the total herbicide-tolerant seed price. Because the traditional and herbicide-tolerant seed prices were assigned probability distributions, @Risk did not select the same seed prices in the two simulations, thus causing the seed companies' surplus to differ between the two data sources.

surpluses to represent larger proportions of the total worldwide gain. Like MLS, the innovators of the technology captured a large share of the total benefits (elasticity-based estimates).

U.S. consumers benefited from the technology since the increase in the soybean supply lowered the commodity's price by 1.2 cents per bushel to 9.5 cents per bushel (table 5). The gains realized by domestic consumers using the two data sources are comparatively smaller than those obtained by the innovators and U.S. farmers (about 5 to 13 percent of the total benefits). Many analyses (including $FZ_a$ and MLS) find that the U.S. consumers' portion of the benefits is small since the herbicide-tolerant trait is designed for farmers rather than consumers, allowing farmers to more effectively control weeds.

The ROW also gained from the adoption of herbicide-tolerant soybeans. While the net change in surplus was positive, foreign producers realized a loss due to the planting of herbicide-tolerant soybeans worldwide. Except in Argentina, the adoption of herbicide-tolerant varieties outside of the U.S. was minimal in 1997.[6] As a result, most foreign producers faced a lower world price without having the yield gains and reductions in weed control costs. ROW consumers, on the other hand, profited from lower soybean prices. On a net basis, the ROW earned $19.5 million with the elasticity-based farm-level impacts (6 percent of the total world benefits) and $231.5 million with the mean ARMS data (22 percent of the total surplus).

## Conclusion

The size and distribution of the benefits arising from the adoption of biotech crops vary significantly, depending on the farm-level effects and the supply and demand elasticity assumptions for the domestic and world markets. Estimates of the benefits derived from the

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

elasticity-based approach and the EMD data appear to be more plausible than those obtained from the ARMS survey because the farm-level impacts obtained from the first two sources are attributed more to biotechnology.

This study does not lend support to the popular belief that U.S. farmers received at least one-half, or as much as over two-thirds, of the total benefits realized from the adoption of biotechnology (McHughen, Paarlberg). Rather, results of this study indicate that in 1997, U.S. farmers realized considerably less than half of the total benefits. The bulk of the benefits appear to have gone to the gene supplier, seed companies, U.S. consumers, and the rest of the world.

Estimates of the benefits for producers and consumers in the domestic and international markets in this study could potentially be biased upward because a parallel shift in the supply function is assumed in estimating Marshallian surplus. To the extent that the shift is nonlinear, the area of the surplus measure is overstated in this study as market prices move away from the equilibrium level. However, the bias does not appear to be significant for most stakeholders (other than the rest of the world) in the case of herbicide-tolerant soybeans in 1997.

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