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.	1997-Low elasticity[2]	1,100	77	10	4	9
(2000a)	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 world-wide 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.