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

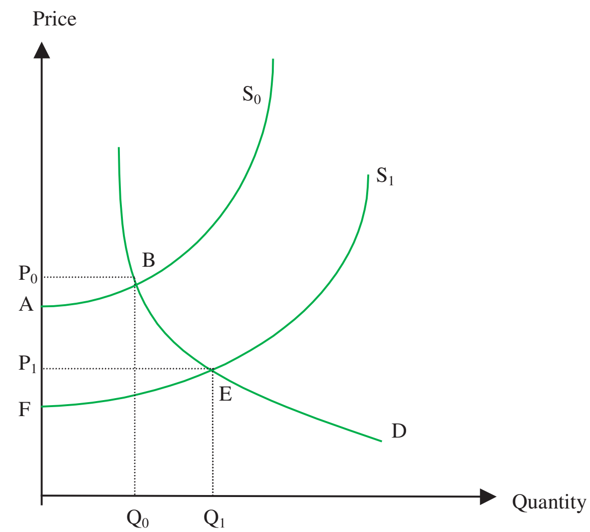
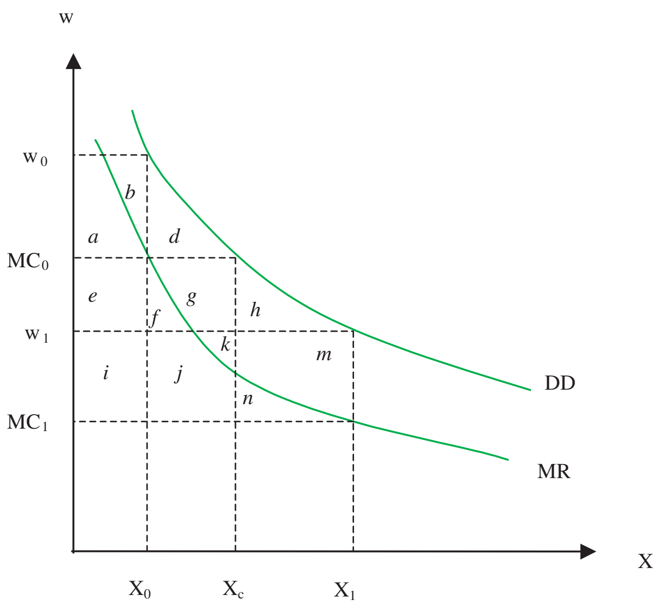


Figure 4
Drastic innovation in the input market



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.

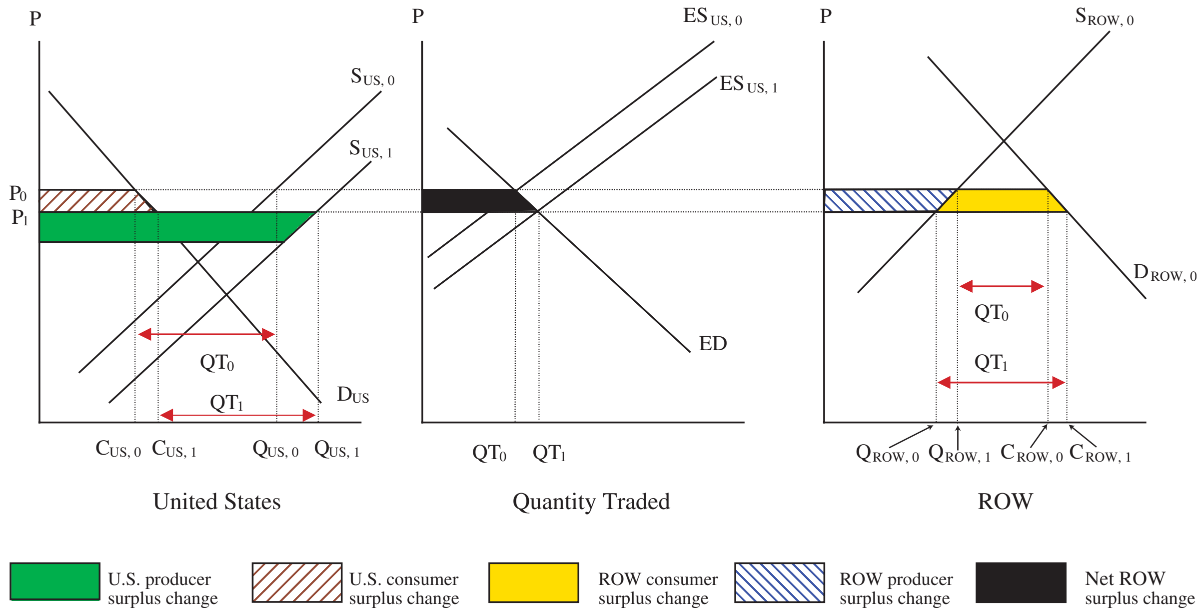
If biotech crops are not available to ROW producers, only the U.S. supply curve moves. On the other hand, if biotech crops are available worldwide, then both the U.S. and ROW supply curves shift to the right. The extent to which the ROW supply curve shifts to the right depends on the efficiency of technology 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.