Microeconomic Impact of Adopting Bioengineered Crops

Faced with reduced returns to crop production caused by low commodity prices, farmers are examining alternative technologies as ways to improve financial performance by cutting costs and/or increasing yields. Rapid adoption of GE crop varieties among farmers suggests that these technologies are perceived to have advantages over traditional methods. GE crop varieties with pest management traits provide a broad spectrum of potential benefits and appeal to farmers because they promise to simplify pest management, reduce its costs, increase its effectiveness, and increase flexibility in field operations. But impacts vary by crop and technology and are often confounded with other factors, making it difficult to isolate the effect of adopting GE crop varieties on yield and profits. For example, the physical environment of the farm (e.g., weather, soil type) affects profitability directly through increased fertility and indirectly through its influence on pests.

This section examines the economic impact of GE crop adoption on U.S. farms. Has the adoption of GE crop varieties affected the economic performance of U.S. farm businesses? If so, how has the impact varied across farms? To accomplish this objective, the impacts of adoption on corn, soybean, and cotton producers are evaluated using both 1997 field-level and 1998 whole-farm survey data.[16] Field-level data provide more accurate information regarding yields and input uses; whole-farm data allows the calculation of broader measures of farm financial performance. In both cases, the analyses shown in this report can be considered as a marginal analysis, meaning that the estimated financial impacts are associated with changes in adoption around the aggregate level of adoption.

Econometric Models

Field-Level Analysis

The field-level analysis used the econometric model developed by Fernandez-Cornejo, Klotz-Ingram, and Jans (1999) to estimate the impact of adopting GE crops on yields and net returns using 1997 field-level survey data. The model takes into consideration that farmers' adoption and pesticide use decisions may be simultaneous (Burrows, 1983). In addition, the model corrects for self-selection.[17] Finally, the model is consistent with farmers' desire to maximize profits (Fernandez-Cornejo, Klotz-Ingram, and Jans, 1999; Fernandez-Cornejo and McBride, 2000).

The field-level analyses include herbicide-tolerant soybeans, herbicide-tolerant cotton, and Bt cotton. Each technology was modeled individually using 1997 survey data. Each model included pest infestation levels, other pest management practices, crop rotations, and tillage. Geographic location was included as a proxy for soil, climate, and other local factors that might influence the impacts of adoption. Net returns (in this context also called gross margin and variable profits) are defined as per-acre revenues minus per-acre variable expenses, including pesticides, seed (including technical fee), and labor.

Results of such modeling are expressed as elasticities. In our context, an elasticity is the relative change in a particular measure (e.g., yields, profits) relative to a small relative change in adoption of the technology from current levels. The results can be viewed in terms of aggregate impacts across the entire agricultural sector as more producers adopt the technology, or in terms of a typical farm as they use the technology on more of their land. As with most cases in economics, the elasticities estimated in the quantitative model should only be used to examine small changes (say, less than 10 percent) away from current levels of adoption.

Whole-Farm Analysis

The whole-farm analysis assesses the impact of adopting GE crops on farm financial performance using the econometric model shown in appendix III. The model uses 1998 farm-level survey data described in box 1 (pp. 5-7). By controlling for several other factors that may also affect financial performance—such as economic and environmental conditions, management practices, and operator characteristics—

[16] Corn and soybeans are leading users of agricultural pesticides at a substantial cost to U.S. farmers. These two crops comprised about 70 percent of the herbicide poundage, and more than 20 percent of the insecticide poundage used on major U.S. field crops in 1995 (Fernandez-Cornejo and Jans, 1999). Average chemical costs for corn, at $28 per acre, are nearly 20 percent of operating costs. Chemical costs average about $25 per acre for soybeans, comprising about a third of total operating costs (USDA, ERS, 2000a).

[17] Self-selection arises because farmers are not assigned randomly to the two groups (adopters and nonadopters), but make the adoption choices themselves. Therefore, adopters and nonadopters may be systematically different and these differences may manifest themselves in farm performance and could be confounded with differences due purely to adoption (Greene, 1997).

the model attempts to isolate the effect of GE crop adoption on farm financial performance.

Separate models were estimated for herbicide-tolerant corn, Bt corn, and herbicide-tolerant soybeans. The models were specified using variables that have shown to be related to technology choice in previous research (box 2, pp. 14-15). Several measures of farm financial performance were examined, but results are reported for only two measures: net returns per tillable acre and modified net farm income per tillable acre.[18]

Net returns were measured as gross value of crop production minus total farm chemical and seed expenses, where gross value of crop production is the production of each crop commodity produced on the farm operation valued at the State-average price received by farmers (USDA, NASS, 1999a). This measure of financial performance was used because most of the financial impacts of adopting GE crops result from changed crop yields, reduced chemical costs, and increased seed costs. Thus, this measure captures the greatest influence that GE crop adoption would have on whole-farm financial performance as it filters out the impact that other farm activities —such as livestock production, custom work, and government program participation— have on financial performance. Moreover, this measure is consistent with the "net returns" variable used in the field-level analysis as well as other studies on the relative economies of GE and conventional crops (box 3).

Modified net farm income was measured as net farm income (NFI) plus interest expense. NFI was calculated as gross farm income minus total farm operating expenses (excluding marketing expenses). The measure of net farm income used in this analysis measures the return to operator and unpaid family labor, management, and capital (both equity and borrowed). Interest expenses are added back to net farm income so that variation in farm debt does not influence the financial comparison among farms. Because of the influence of several factors on MNFI, the impact of GE crop adoption would need to be relatively strong in order to have a significant effect on MNFI.

[18] Other financial performance measures examined in this study were an estimate of operator labor and management income (net farm income less charges for unpaid labor and capital) per tillable acre and rate of return to assets. These results were very similar to those obtained for the net farm income measure.

The whole-farm analysis of the impact of adopting GE corn (soybeans) was conducted on two segments of the farm population: (1) operations that harvested one or more acres of corn (or soybeans), and (2) operations that specialized in the production of corn (or soybeans), with more than 50 percent of the total value of farm production from corn (soybeans). Such specialized farms were examined in addition to all growers because GE technologies likely have the greatest financial impact on operations specializing in the target commodities.

The whole-farm analysis also examined the effect of spatial variation on the impact of GE crop adoption using the ERS farm resource regions (box 1). Because pest infestations differ across the country, one would expect the impacts of pest control measures such as GE crops to be greatest where target pest pressures are most severe. Research suggests that the value of Bt corn relative to conventional varieties increases as one moves from east to west in the Corn Belt, because ECB infestations are much more frequent and severe in the western Corn Belt (Hyde et al., 2000). Also, weed pressure tends to be greatest in the eastern and southern United States because of the hot, moist climate and the longer growing season. Therefore, the expected returns of herbicide-tolerant crops would be greater in these areas because of higher costs for conventional weed control.[19]

Empirical Results

Field-Level Results

GE crops available for commercial use do not increase the yield potential of a variety. In fact, yield may even decrease if the varieties used to carry the herbicide-tolerant or insect-resistant genes are not the highest-yielding cultivars. However, by protecting the plant from certain pests, GE crops can prevent yield losses compared with non-GE varieties, particularly when infestation of susceptible pests occurs. This effect is particularly important in Bt crops. For example, before the commercial introduction of Bt corn in 1996, the European corn borer (ECB) was only partially

[19] The farm resource regions are used to reflect agro-climatic variation across the country and the differences in pest pressures this creates. One change to the regional delineation is that the Heartland is divided along the Mississippi River into the East Heartland and the West Heartland. This change better reflects the difference in weed and ECB pressure between these areas.

Box 3—Previous Research on the Economic Impact of GE Crop Adoption

Published research about the economic benefits from using herbicide-tolerant crops has been mixed. Data from field trials in West Tennessee were used in an economic analysis of Roundup Ready soybeans (Roberts, Pendergrass, and Hayes, 1999). Comparing per acre net returns from 14 trials, the returns from the Roundup system were 13 percent higher than the returns for the second most profitable system. Higher returns from the Roundup system resulted from both higher yields and lower herbicide costs. Research results from experimental trials in Mississippi (Arnold, Shaw, and Medlin, 1998) also showed higher yields and net returns from Roundup Ready soybeans versus conventional varieties. Other partial budgeting results also showed higher returns from Roundup Ready versus conventional weed control for soybeans (Marra, Carlson, and Hubbell, 1998; Reddy and Whiting, 1999). However, research using experimental data on Roundup Ready and conventional corn varieties in Kentucky did not show a significant difference in returns above seed, herbicide, and fixed costs (Ferrell, Witt, and Slack, 1999).

While economic analyses based on experimental data have mostly favored herbicide-tolerant crops over conventional varieties, results from producer surveys have not been as definitive. Research using data from 1997 and 1998 cost of production surveys in Mississippi suggested that pesticide costs were lower with Roundup Ready soybeans, but lower pesticide costs were offset by the added technology fee (Couvillion et al., 2000). McBride and Brooks (2000) compared mean seed and pest control costs estimated from a 1997 national survey of soybean producers. Results of the comparison did not indicate a cost advantage, or disadvantage, for herbicide-tolerant versus other soybean varieties. Using the same data, Fernandez-Cornejo, Klotz-Ingram, and Jans (1999) developed an econometric model to estimate the impact of adoption on net returns after other factors, including cropping practices, agronomic conditions, and producer characteristics, were statistically controlled. Results of this study also did not show a significant change in net returns to soybean production from the adoption of herbicide-tolerant soybeans. Similar results were obtained in an analysis of the impacts from adopting herbicide-tolerant corn (Fernandez-Cornejo and Klotz-Ingram, 1998).

Published research about the economic benefits from using Bt corn suggests that the value of Bt corn relative to traditional varieties depends primarily upon the yield loss that can be attributed to damage from the ECB. Results from field trials controlling the level of ECB infestation indicated that at the highest ECB injury level, Bt corn hybrids yielded more than 10 bushels per acre more than conventional varieties (Graeber, Nafziger, and Mies, 1999). The authors concluded that at $2.25 per bushel corn, and $12 per acre for the Bt technology, it takes about 5 bushels per acre more yield to pay for the ECB protection. Similar results were reported by Rice and Pilcher (1998) who showed how returns to Bt corn vary with the expected corn yield, the number of corn borers per plant, and the effectiveness of pest control. Because the economic benefits from Bt corn are tied to the level of ECB infestation, studies in some areas have found that the value of protection from Bt corn is not likely to exceed its cost. Hyde et al. (1999) found that the value of protection offered by Bt corn under Indiana conditions is generally lower than the premium paid for Bt seed corn. Similarly, research under Wisconsin conditions suggests that Bt seed may not be worth the additional cost because of a low probability of infestation (Lauer and Wedberg, 1999). Research by Hyde et al. (2000) suggests that the value of Bt corn relative to conventional varieties increases as one moves from east to west in the Corn Belt because ECB infestations are much more frequent and severe in the western Corn Belt.

controlled using chemical insecticides. The economics of chemical use were not always favorable and timely application was difficult, so farmers often accepted yield losses (of 3 to 6 percent per one corn borer per plant depending on the stage of plant development) rather than incur the expense.

From this perspective, for the cases analyzed, the empirical results are not surprising. Adoption of herbicide-tolerant soybeans led to a small but statistically significant increase in yield while adoption of Bt cotton led to a large increase in yields (table 5). A 10-percent increase in the adoption of herbicide-tolerant soybeans led to a 0.3-percent increase in yields (elasticity of yields is +0.03).[20] On the other hand, an increase of 10 percent in the adoption of adoption of Bt cotton in the Southeast increased yields by 2.1 percent (elasticity is +0.21).[21]

The adoption of herbicide-tolerant cotton also has a positive and statistically significant effect on net returns (elasticity is +0.18), as does the adoption of Bt cotton (elasticity of +0.22). However, the adoption of herbicide-tolerant soybeans does not have a statistically significant effect on net returns (table 5). As discussed in more detail in a later section, the soybean results appear to be inconsistent with the rapid adoption of this technology. Yet, other factors have a considerable impact on adoption, namely the simplicity and flexibility of the weed control program, which frees up valuable management time for other activities. However, it is difficult to measure management involvement on various technologies from survey data.

Whole-Farm Results

GE crop adoption was found to affect net returns on specialized corn farms. Adoption of herbicide-tolerant corn had a positive and statistically significant effect on net returns, but the elasticity of net returns with respect to adoption was negative for Bt corn (table 5). The effect of GE crop adoption on farm financial performance was not significant for soybean farms.

An analysis using broader financial performance measures (including net farm income and return on assets) did not show GE crops to have a significant impact. GE crop technologies do not require a capital investment and, thus, their impact on farm finances is mainly limited to changes in variable costs and returns. For this reason, adoption-impact models are likely to be more useful in explaining net returns than in explaining farm income.[22]

The impact of GE crops on the net returns of specialized corn farms varied by region (table 6). On all specialized corn farms nationwide, a 10-percent increase in herbicide-tolerant corn led a 2.7-percent rise in net returns. But in the eastern Heartland, the increase in net returns expanded to 4.1 percent, consistent with high weed pressures there. In contrast, the adoption of Bt corn led to a decrease in net returns among specialized corn farms; as adoption increased

[20] Adoption of herbicide-tolerant cotton also led to significant yield increase in 1997 (elasticity of +0.17).

[21] The analysis of Bt cotton focused on the Southeast region because States there show much higher rates of adoption of Bt cotton than other regions (Falck-Zepeda and Traxler, 1998) and infestation levels of pests nontargeted by Bt appear to be more important than Bt target pests in the rest of the cotton-producing States.

[22] Previous studies have had much more success in explaining the variation in net farm income (El-Osta and Johnson, 1998; Haden and Johnson, 1989). However, these studies generally did not attempt to isolate the impact of specific technologies, or if they did, focused on technology adoption for enterprises that comprised a substantial portion of whole-farm business activity (e.g., dairy). Business activity from enterprises unrelated to the GE crops, such as livestock, could have interfered with the measurement of any impact that GE crop adoption had on net farm income.

Table 5—Impact of adoption of herbicide-tolerant and insect-resistant crops on yields and net returns, 1997-98

	Elasticity with respect to probability of adoption of					
	Herbicide-tolerant				Insect-resistant (Bt)	
Item	Soybean		Cotton	Corn[1]	Cotton	Corn
	1997	1998	1997[2]	1998	1997	1998
Elasticity of [3]						
Yields	+0.03	na[4]	+0.17	na	+0.21	na
Net returns[5]	0[6]	0[6]	+0.18	+0.27	+0.22	-0.34
Unit of observation	field	whole farm	field	whole farm	field	whole farm

[1] Specialized farms.
[2] Southeast region.
[3] An elasticity is the relative change in a particular impact (e.g., yields, profits) relative to a small relative change in the (probability of) adoption of the technology from current levels.
[4] Not available.
[5] Gross value of production minus variable cost (chemicals and seed expenses).
[6] Statistically innsignificant underlying coefficient.

Table 6—Elasticities of net returns with respect to the probability of GE crop adoption among specialized corn farms, by region, 1998

Region	Net returns Herbicide-tolerant corn	Net returns Bt corn
U.S.	0.27	-0.34
Eastern Heartland	0.41	-0.46
Western Heartland	0.19	-0.27
Northern Crescent	0.17	-0.24*
Prairie Gateway	0.31*	-0.32*
Other regions	0.19	-0.49*

*Indicates that underlying coefficient is not statistically significantly different from that of the Eastern Heartland region.

by 10 percent, returns declined by 3.4 percent. This effect was much less in the western Heartland than the eastern (elasticity of -0.27 versus -0.46). Corn borer pressure is greater in portions of the western Heartland, as are the benefits of its relief.

Interpretation of Results on Adoption and Net Returns

Perhaps the biggest issue raised by these results is how to explain the rapid adoption of GE crops when farm financial impacts appear to be mixed or even negative. Both herbicide-tolerant cotton and Bt cotton showed positive economic results, so rapid growth in adoption is not surprising in these cases. However, since adoption of herbicide-tolerant corn appears to improve farm financial performance among specialized corn farms, why is its adoption relatively low? Even more puzzling, the adoption of herbicide-tolerant soybeans and Bt corn has been rapid, even though we could not find positive financial impacts in either the field-level nor the whole-farm analysis.

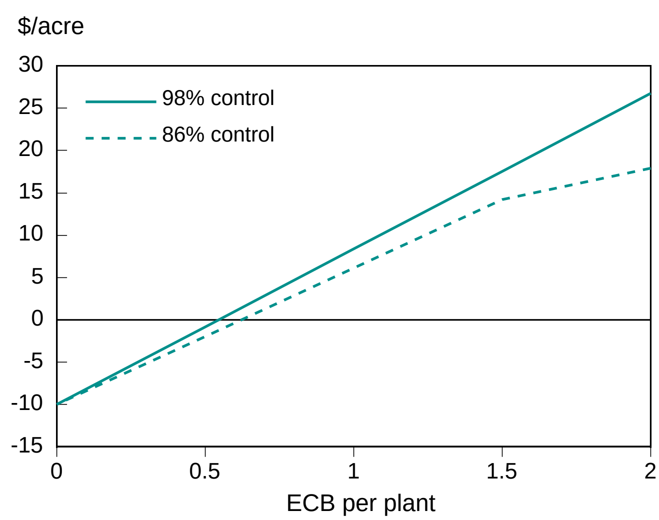
The financial benefits of adopting herbicide-tolerant corn may be due in part to seed companies setting low premiums (including technology fees) relative to conventional corn varieties in an attempt to expand market share. Also, the limited acreage on which herbicide-tolerant corn has been used is likely acreage with the greatest comparative advantage for this technology, boosting its financial benefits.

For herbicide-tolerant soybeans, the nonsignificant economic impact obtained in this study, using both 1997 field data and 1998 whole-farm data, is consistent with findings from other recent producer surveys (Duffy, 2001; Couvillion et al., 2000). For example, Duffy concludes that there is essentially no difference in returns from using herbicide-tolerant soybeans versus traditional (nontolerant) soybeans. This suggests that, given the high extent of adoption of herbicide-tolerant soybeans, other considerations may be motivating farmers.

A primary motivation may be the simplicity and flexibility of the herbicide-tolerant program (Carpenter and Gianessi, 1999), which allows growers to use one product instead of several herbicides to control a wide range of both broadleaf and grass weeds, and also makes harvest "easier and faster" (Duffy, 2001). [23] Herbicide-tolerant crops also fit into ongoing trends toward postemergence weed control, conservation tillage practices, and narrow row spacing. In addition, the window of application for glyphosate is wider than for other postemergence herbicides, allowing growers to treat later with less concern about getting poor weed control or injuring the crop. Because glyphosate has no residual activity, carryover restrictions are not a problem, giving growers more rotation options. Glyphosate is also effective at controlling weeds that are resistant to other classes of herbicides (Carpenter and Gianessi, 1999).

[23] The simplicity and flexibility of pest control programs are difficult to measure and quantify from survey data. Management (operator) time used in supervising production may be an indicator of the relative convenience of alternative production systems, but a meaningful measure of management time dedicated to a particular technology and crop could not be obtained from the data.

Figure 8
Potential returns to Bt corn



Source: Data from Rice and Pilcher (1998).

The economic potential of Bt corn on an individual farm is more difficult to evaluate because returns to Bt corn are realized only if the density of European corn borer (ECB) is sufficient to cause economic losses greater than the premium paid for the Bt seed (fig. 8). This requires farmers to forecast infestation levels and input and corn prices before planting, prior to observing an infestation. By one account, only 25 percent of corn acreage was infested with ECB at a treatable level in 1997 (Pike, 1999). This would conform with Bt corn adoption rates of 19 percent of the corn acreage in 1998 and 26 percent in 1999 (fig. 1).

Our results show that, on the margin, the adoption of Bt corn had a negative impact on the farm financial performance of specialized corn farms in 1998. This suggests that Bt corn may have been used on some acreage where the value of ECB protection was lower than the Bt seed premium. This "overadoption" may derive from annual variations in ECB infestations, as well as poor forecasts of infestation levels, corn prices, and yield losses due to infestations.[24] Overadoption may also arise from the desire of some risk-averse farmers to insure against ECB losses.

Limitations

Our results should be interpreted carefully since just 2 years of data were examined. The financial impacts of GE crops vary with several factors, most notably annual pest infestations, seed premiums, prices of alternative pest control programs, and any premiums paid for segregated crops. These factors will likely continue to change over time as technology, marketing strategies for GE and conventional crops, and consumer perceptions of GE crops evolve.

[24] With Bt corn adoption slipping to 19 percent in 2000 and 2001, producers may be responding to lower returns in previous years.