Summary

Rapid adoption of new technologies within the U.S. agricultural sector has resulted in sustained increases in agricultural productivity, contributed to economic growth, and ensured an abundance of food. More recently, U.S. farmers are adopting biotechnology innovations that, beyond their impact on productivity, have caused concerns about their potential impact on the environment and opened a Pandora's box of issues surrounding consumer choice, particularly in Europe. These innovations (bioengineered crops) are embedded in the seeds and derive from the use of genetic engineering techniques, which modify organisms by recombinant DNA.

This report summarizes and synthesizes research findings addressing farm-level adoption of genetically engineered (GE) crops. Because there are nonfarm concerns about the technology, an accurate read on benefits and costs to farmers is an important component of a more complete social welfare calculus. Chief among the priorities of this research, given available data, were the following research questions. What is the extent of adoption of first-generation bioengineered crops, their diffusion path, and expected adoption rates over the next few years? What factors have affected the adoption of bioengineered crops and how? And what are the farm-level impacts of the adoption of bioengineered crops available as of the 1990s?

The most widely and rapidly adopted bioengineered crops in the United States are those with herbicide-tolerant traits. These crops were developed to survive the application of specific herbicides that previously would have destroyed the crop along with the targeted weeds, and provide farmers a broader variety of herbicide options for effective weed control. Herbicide-tolerant soybeans became available to farmers in limited quantities in 1996. Use expanded to about 17 percent of the soybean acreage in 1997, 56 percent in 1999, and 68 percent in 2001. Herbicide-tolerant cotton expanded from 10 percent of cotton acreage in 1997 to 42 percent in 1999, and reached 56 percent in 2001. In contrast, the adoption of herbicide-tolerant corn has been much slower and has yet to exceed 10 percent.

Bt crops containing the gene from a soil bacterium, *Bacillus thuringiensis*, are the only insect-resistant GE crops commercially available as of 2002. The bacteria produce a protein that is toxic to certain Lepidopteran insects (insects that go through a caterpillar stage), protecting the plant over its entire life. Bt has been built into several crops, including corn and cotton. After its introduction in 1996, Bt corn grew to 8 percent of U.S. corn acreage in 1997 and 26 percent in 1999, but fell to 19 percent in 2000-01. Bt cotton expanded rapidly from 15 percent of U.S. cotton acreage in 1997 to 32 percent in 1999 and about 37 percent in 2001.

The growth rate of Bt crop adoption will vary over time, both in a positive and a negative direction, mainly as a function of the infestation levels of Bt target pests. The growth rate for Bt corn adoption is likely to be low since adoption has already occurred where Bt protection can do the most good. On the other hand, adoption of herbicide-tolerant crops will likely continue to grow, particularly for cotton, unless there is a radical change in U.S. consumer sentiment. In most cases, the growth of GE crops estimated in this report is validated by the 2001 plantings.

The adoption of herbicide-tolerant soybeans is found to be invariant to farm size, as expected since GE crop technologies only require changes in variable inputs (such as seeds), which are completely divisible. However, the adoption of

herbicide-tolerant and Bt corn is found to be positively related to farm size. For herbicide-tolerant corn, this appears due to its low overall adoption rate, which implies that adopters were largely innovators and other early adopters. As other researchers have observed, adoption is more responsive to farm size at the innovator stage and this effect generally diminishes as diffusion increases. The observed relationship between Bt corn adoption and farm size may have arisen because Bt corn targets a pest problem that is generally most severe in areas where operations growing corn are largest.

GE crop adoption is found to be positively and significantly related to operator education, experience, or both. More educated or experienced operators are more likely to understand that the greatest economic benefits of new technologies accrue to early adopters. The use of contracting (marketing or production) is positively associated with GE crop adoption in most cases, possibly reflecting the greater importance placed on risk management by adopting farms. Contracting also ensures a market for GE crops, reducing price and any market access risk that could result from uncertain consumer acceptance.

Farm-level impacts of GE crop adoption vary by crop and technology. Our estimates are based on 1997 field-level data and 1998 whole-farm data and are obtained from marginal analyses, meaning that the estimated impacts are associated with changes in adoption around the aggregate level of adoption.

The adoption of **herbicide-tolerant corn** improved farm net returns among specialized corn farms (deriving more than 50 percent of the value of production from corn). The limited acreage on which herbicide-tolerant corn has been used is likely acreage with the greatest comparative advantage for this technology. The positive financial impact of adoption may also be due to seed companies setting low premiums for herbicide-tolerant corn relative to conventional varieties in an attempt to expand market share.

The adoption of **herbicide-tolerant soybeans** did not have a significant impact on net farm returns in either 1997 or 1998. Since these findings were obtained from marginal analysis, they imply that an increase from the average adoption rate (45 percent of acreage) in 1998 would not have a significant impact on net returns. However, this is not to say that GE crops have not been profitable for many adopting farms. As a recent study comparing weed control programs found, the use of herbicide-tolerant soybeans was quite profitable for some farms, but the profitability depended specifically on the types of weed pressures faced on the farm and on other factors. This suggests that other factors may be driving adoption for some farms, such as the simplicity and flexibility of herbicide-tolerant soybeans, which allow growers to use one product instead of several herbicides to control a wide range of both broadleaf and grass weeds, and makes harvest “easier and faster.” However, management ease and farmer time savings are not reflected in the standard calculations of “net returns to farming.”

Adoption of **Bt cotton** had a positive impact on net returns among cotton farms but adoption of **Bt corn** had a negative impact on net returns among specialized corn farms. This marginal analysis suggests that Bt corn may have been used on some acreage where the value of protections against the European corn borer (ECB) was lower than the Bt seed premium. Because pest infestations differ across the country (for example, ECB infestations are more frequent and severe in the

western Corn Belt), the economic benefits of Bt corn are likely to be greatest where target pest pressures are most severe. Some farmers may also have made poor forecasts of infestation levels, corn prices, and yield losses due to infestations. A reduction in the Bt corn adoption rate between 1999 and 2000-01, from 25 to 19 percent, may be due in part to producers learning where this technology can be used profitably.

On the environmental side, our analysis shows an overall reduction in pesticide use related to the increased adoption of GE crops (Bt cotton; and herbicide-tolerant corn, cotton, and soybeans). The decline in pesticide use was estimated to be 19.1 million acre-treatments, or 6.2 percent of total treatments (1997). Total active ingredients also declined by about 2.5 million pounds. The pounds of active ingredients applied to soybeans increased slightly, as glyphosate was substituted for other synthetic herbicides. However, this substitution displaced other synthetic herbicides that are at least three times as toxic to humans and that persist in the environment nearly twice as long as glyphosate.

Results presented in this report should be interpreted carefully, especially since the impact studies are based on just 2 years of survey data. The extent and 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 continue to change over time as technology, marketing strategies for GE versus conventional crops, and consumer perceptions evolve. Finally, the most widely touted farmer benefits of herbicide-tolerant seeds –that it is just plain easy to use and less management intensive—do not get captured by the standard measurement of net returns to management and own labor. Future surveys and analyses will correct for this weakness in our own standard economic yardstick.