Adoption of Bioengineered Crops

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Introduction

Technological change has been acknowledged as a critical component of productivity and economic growth (Solow, 1994; Griliches, 1995). The rapid adoption and diffusion of new technologies within the U.S. agricultural sector has resulted in sustained agricultural productivity growth and ensured an abundance of food (Huffman and Evenson, 1993; Alston and Pardey, 1996; Ball et al., 1997). However, since technological change can affect employment, trade, real wages, and profits, the adoption of new technologies may trigger asymmetric effects on different sectors of the economy.

International competitiveness and environmental issues have also been linked to technological innovation and adoption (Stoneman, 1995). Furthermore, technology policy issues have surfaced during discussions about the appropriate role of the public sector (e.g., level of public research and development funding) in fostering new innovations and promoting their adoption (Feder and Umali, 1993). Because of the economic opportunities and challenges that new technologies offer, the technology innovation and adoption process continues to interest economists, sociologists, and policymakers.

Economists and sociologists want to understand what causes adoption rates to differ and what constrains the rapid adoption of innovations. Several researchers have examined the influence of farmers' attributes on the adoption of agricultural innovations (Rahm and Huffman, 1984; Caswell and Zilberman, 1985). In the past, most adoption studies focused on technological innovations that increase productivity. Studies have since shifted their focus toward adoption of agricultural technologies that affect environmental quality and conserve scarce natural resources. Thus, during the 1970s and 1980s, studies proliferated on the adoption of environmentally preferable technologies such as IPM (Fernandez-Cornejo, Jans, and Smith; 1998).

More recently, U.S. farmers are adopting biotechnology innovations that, beyond their impact on productivity, have also caused environmental and consumer concerns, particularly in Europe. These innovations (bioengineered crops) are embedded in the seeds and derive from the use of genetic engineering (GE) techniques.

Genetic engineering modifies organisms by recombinant DNA techniques. These techniques allow a more precise and time-saving alteration of a plant's traits, facilitating the development of characteristics that are not feasible through traditional plant breeding. Genetic engineering also allows scientists to target a single plant trait, thus decreasing the number of unintended characteristics that often accompany traditional breeding techniques, and increasing the speed at which breeders can develop new varieties. The first generation of bioengineered crops includes crops with pest management traits, including crops carrying genes (such as the gene from the soil bacterium Bt, *Bacillus thuringiensis)* selected for resistance to certain insects and/or tolerance to specific herbicides.

This report discusses the adoption of GE crops with pest management traits, which has risen dramatically since commercial introduction in the mid-1990s. Issues related to the adoption of these bioengineered crops—including farm impacts, consumer acceptance, environmental safety, and others—are among the leading concerns affecting U.S. agriculture. Because of the controversy surrounding these issues and the continual introduction of new technologies, there is great need for objective measurement and analysis of all components of overall social welfare implications of GE crops—including the farm-level impacts.

Factors Shaping Adoption of Bioengineered Crops

An innovation's profitability, compared with traditional alternatives, has been regarded as the primary motivation behind adoption. This would suggest that the widespread adoption of genetically engineered crops follows from their perceived profitability over traditional methods. However, other factors like producer flexibility, consumer preferences, and farmer attributes and perceptions also influence adoption.

Producer Profitability

The impacts of GE crops on farm profitability vary greatly by region, crop, and technology. Impacts also vary with seed premiums, crop prices, and prices of alternative pest control programs. Moreover, some factors that influence adoption of GE crops are difficult to measure (for example, the economies in management time associated with the adoption of herbicide-tolerant crops). Finally, profits may be affected by factors other than GE adoption, such as other cropping practices, weather, or management ability, making it difficult to isolate the effect of GE crop varieties.

Producers of *herbicide-tolerant crops* versus traditional crops benefit mainly from lower costs. They expect to achieve at least the same output while lowering weed control costs for chemicals, chemical applications, mechanical tillage, and scouting. In return, producers pay more to seed companies for the herbicide-tolerant seed. Thus, the profitability of the herbicide-tolerant program depends on weed control cost savings compared with seed cost premiums. Seed companies aim to set the seed price high enough to obtain as much of the farmers' savings in weed control costs as possible, while still inducing the producer to use the herbicide-tolerant seed. In addition, the substitution of glyphosate, used in most herbicide-tolerant programs, for other herbicides decreases the demand for those herbicides. Thus, the prices of other herbicides decrease, lowering production costs even for those farmers not using the herbicide-tolerant crops.

Other factors believed to affect the economics of adoption of herbicide-tolerant crops are the simplicity and flexibility of the weed control program. Herbicide-tolerant programs allow growers to use one product instead of several herbicides to control a wide range of both broadleaf and grass weeds without sustaining crop injury. Thus, herbicide-tolerant crops appear to free up valuable management time for other activities. However, standard measures of net returns to management (used in this and other studies of this nature) have not been designed to quantify how management intensive a technology is in dollar terms.

Potential users of *Bt crops* (Bt corn or cotton) face a complex decision in determining the relative profitability of these technologies. The use of Bt seed can reduce costs by virtually eliminating the application of insecticides intended to control Bt target pests. More important, because chemical insecticides are not as effective as the control achieved with Bt seed, planting Bt seed increases crop yields, as crop losses are reduced. Therefore, Bt crops are more profitable than traditional insect control measures only if the target pest infestations are severe enough to cause economic losses greater than the economic impact of the price premium paid for the Bt seed. However, unlike annual weed infestations that are relatively stable and predictable, insect infestations can vary dramatically each year (Gray and Steffey, 1999). Since the decision to plant Bt crops must be made prior to observing the insect infestation, the farmer may or may not make the most economical decision for a given year depending upon the resulting infestation. Thus, Bt crops act as insurance against significant losses that may occur in the event of severe pest infestations.

Consumer Preferences

Consumers express their preferences for bioengineered crops at the market and producers must respond to the economic signals that these preferences convey. Factors influencing consumer preferences include (1) their perceptions of benefits and risks of bioengineered crops on human health and the environment, (2) their ethical stance toward genetic engineering, and (3) their trust in government regulations concerning risk assessment and management (OECD, 2000). The importance of these factors has varied substantially among consumers both within and among countries, causing significant uncertainty about the acceptance of bioengineered crops, particularly in international markets. This uncertainty may discourage adoption of these crops, particularly food crops.[1] In addition, specific markets for nonbiotech crops have emerged as consumers have expressed their preferences.

Environment

While many of the environmental benefits and risks of GE crop adoption are dificult to quantify, changes in pesticide use associated with the adoption of GE crops are surely an important effect of GE crops (Royal

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[1] Cotton is a particular case. While food safety concerns may not be limiting for most consumers of the cotton fiber, there may be some concern related to the use of cotton seed. In addition, there may be environmental concerns in some sector of the market for cotton fiber that limits the demand for herbicide-tolerant cotton at the margin.

Society, 1998; Henry A. Wallace Center, 2000). Several recent polls among consumers indicate that consumers were willing to accept biotechnology as a means of reducing chemical pesticides used in food production (Farm Bureau/Philip Morris Gap Research, 2000). More specifically, consumers would be likely to buy a variety of produce “if it had been modified by biotechnology to be protected from insect damage and required fewer pesticide applications” (IFIC Foundation, 2001).

Other Factors

While profitability (i.e., the extent of yield increases and/or input cost reduction versus the costs of adoption relative to the current management practices) is key to explaining the extent and rate of technology adoption, most studies acknowledge that heterogeneity among farms and farm operators can often explain why all farmers may not adopt an innovation in the short or long run (Khanna and Zilberman, 1997; Batte and Johnson, 1993; Lowenberg-DeBoer and Swinton, 1997). Differences influencing readiness to adopt include farm size, tenure, operator education/experience, and access to information and credit. The nature of the technology or the financial, locational, and physical attributes of the farm may also influence profitability and, ultimately, the adoption decision.

Other factors that may have some effect on adoption include the interaction of GE crops with other cropping practices. For example, the adoption of herbicide-tolerant crops complements the conservation tillage practices and narrow row spacing. Adoption may also have some impact on the safety of farmworkers and other people operating (or living) in nearby areas. For example, as the use of Bt crops ensures that insect control is properly timed and reduces the need to handle and apply synthetic insecticides, it thereby increases farmworker safety and avoids the misapplication or drift of chemicals from the target area (Rice and Pilcher, 1998).

Objectives and Roadmap

USDA’s Economic Research Service (ERS) has studied bioengineered crops and their adoption by farmers since 1998. The farm-level component of this research program addresses the following three questions. What is the extent of adoption of 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? Finally, what are the farm-level impacts of the adoption of bioengineered crops? The GE crops considered in this report include those with herbicide-tolerant and insect-resistant traits—the principal GE crops available to and adopted by U.S. farmers.

Data to address these questions came mostly from surveys conducted by USDA. This report summarizes and synthesizes the findings from several research projects addressing farm-level adoption of GE crops. The appendices include details about some of the projects.

The first section of this report summarizes the extent of adoption of bioengineered crops, including herbicide-tolerant soybeans, corn, and cotton; and Bt corn and cotton. The next section examines the diffusion process of bioengineered crops, and discusses possible adoption paths of these crops through 2002, under different scenarios. Following that, we examine the factors that influence the adoption of GE crops by focusing on adoption in corn and soybean production (i.e., herbicide-tolerant corn and soybeans and Bt corn). In addition, we measure the influence of various factors on the adoption decision, with special emphasis on farm size.

The last, and perhaps most difficult, question is examined in the last two sections. The microeconomic effects of adoption are examined first. In particular, has adoption of GE crop varieties affected the economic performance of U.S. farm businesses and, if so, how has the impact varied across farms? To answer this question, the impacts of adoption on corn, soybean, and cotton producers are evaluated using 2 years of data.

The final section explores the potential impacts from adoption of GE crops on the environment occurring via changes in pesticide use and in tillage practices. A complete analysis of environmental benefits and risks of GE crop adoption is beyond the scope of this report, as data to quantify a range of factors are not available. Still, examining the changes in pesticide use associated with the adoption of GE crops is important in assessing the effects of GE crops (Royal Society, 1998; Henry A. Wallace Center, 2000).