Factors Affecting the Adoption of Bioengineered Crops

Since technological change can affect the level of output, product quality, employment, trade, real wages and profits, the adoption of new technologies offers economic opportunities and challenges. Consequently, understanding the adoption process continues to be of interest to economists, sociologists, and policymakers (box 2). Of particular interest to policymakers is the impact of new technologies on farm structure (i.e., farm size), and the role that farm structure plays in the adoption process.

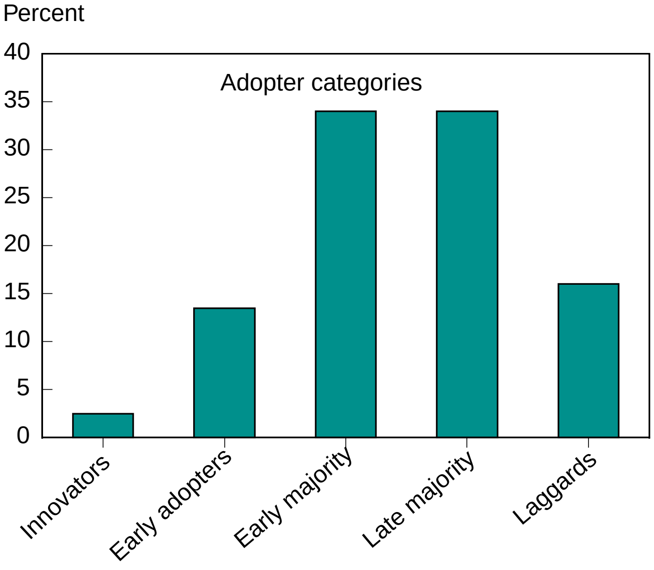
Numerous technology adoption studies have been conducted over the last 40 years, beginning with Griliches (1957) and Rogers (1961) (see box 2). Feder, Just, and Zilberman (1985) and Feder and Umali (1993) review many of these studies. Of note, Rogers (1961, 1995) hypothesized that innovators or early adopters (fig. 6) have attributes different from later adopters or nonadopters. Feder and Umali (1993) distinguish between adoption factors during the early phases of adoption versus the final stages of adoption; factors such as farm size, tenure, education, information, and credit may be significant for the early adopters but not for later adopters.

A few empirical analyses of the factors affecting GE crop adoption of have appeared thus far. Fernandez-Cornejo and McBride (2000) report that larger operations and more educated operators are more likely to use herbicide-tolerant soybeans. They also report that higher crop prices are more likely to raise adoption, while conventional tillage is likely to reduce adoption (farmers use conventional tillage to help control weeds, whereas herbicides are typically used with conservation or no-till practices). Alexander, Fernandez-Cornejo, and Goodhue (2000b) examine the role of risk aversion in producer behavior for corn and soybean producers, finding that risk preferences, as measured by responses to survey questions, are likely to influence the decision to plant GE corn but not soybeans.

The objectives of this section are to: (1) 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), and (2) contrast the relative influence of various factors on the adoption decision for these technologies, with special emphasis on the role of farm size.

Figure 6

Rogers' characterization of adopters



Source: Adapted from Rogers (1983, p. 247).

Modeling Crop Adoption

The factors that influence adoption of genetically engineered crops are examined empirically using econometric techniques, specifically a Tobit model, presented in Appendix II. This model allows the estimation of the likelihood of adoption as well as the extent (i.e., intensity) of adoption. The Tobit model is preferable to binary adoption models when the decision to adopt also involves simultaneously a choice regarding the intensity of adoption (Feder and Umali, 1993), as it does with GE crops.

Results of the Tobit analysis for the adoption of genetically engineered crops are presented in detail in Appendix II, including the estimated coefficients, standard errors, and calculated marginal effects. The marginal effects are used to calculate the elasticities of adoption with respect to each of the significant explanatory variables (table 3). An elasticity of adoption measures the responsiveness of adoption to a particular factor, and is equal to the relative change in adoption of a technology with respect to a small relative change in a given factor (for example, farm size) from current levels. The elasticities obtained from the Tobit model take into account that a change in an explanatory variable will simultaneously affect the number of adopters and the proportion of acreage under adoption. For example, an elasticity of adoption with respect to size equal to 0.26 means that a 10-percent increase from the mean size (harvested acres) leads to an increase in the expected

Box 2—Previous Research on the Factors Affecting Agricultural Technology Adoption

Economists and sociologists have made extensive contributions to the literature on the adoption and diffusion of technological innovations in agriculture (e.g., Feder et al., 1985; Rogers, 1995). Such research typically focuses on the long-term rate of adoption and the factors that influence the adoption decision

The characteristics (perceived or real) of a new innovation are widely known to influence the adoption decision (Rogers, 1995; Batz et al., 1999). Rogers (1995) hypothesized that five technology attributes affect the rate of adoption: relative advantage (i.e., profitability, initial cost, status, time savings, and immediacy of payoff over conventional practice); compatibility (i.e., similarity with previously adopted innovations); complexity (degree of difficulty in understanding and use); trialability (i.e., ease of experimentation); and observability (i.e., degree to which the results of the innovation are visible). Using this characterization, GE crops have several unique attributes that would be expected to impact its adoption rate, including: low initial or fixed cost; high degree of compatibility (i.e., with current weed control practices), low degree of complexity, trialability (i.e., divisible), and observability.

Farm Structure/Size. A basic hypothesis regarding technology transfer is that the adoption of an innovation will tend to take place earlier on larger farms than on smaller farms. Just, Zilberman, and Rausser (1980) note that given the uncertainty, and the fixed transaction and information costs associated with innovations, there may be a critical lower limit on farm size that prevents smaller farms from adopting. As these costs increase, the critical size also increases. It follows that innovations with large fixed transaction and/or information costs are less likely to be adopted by smaller farms. However, Feder et al. (1985) point out that lumpiness of technology can be somewhat offset by the emergence of a service sector (i.e., custom service or consultant) that can essentially turn a nondivisible technology into a divisible one.

Disentangling farm size from other factors hypothesized to influence technology adoption has been problematic. For example, Feder et al. (1985) caution that farm size may be a surrogate for other factors, such as wealth, risk preferences, and access to credit, scarce inputs, or information. Moreover, access to credit is related to farm size and land tenure because both factors determine the potential collateral available to obtain credit. Also, farm size is affected positively by the amount and quality of management labor and, since farm size can be varied in the short run by renting, farm size is also affected by profitability and credit considerations (Gould et al., 1989). And El-Osta and Morehart (1999) point out that the higher tolerance toward risk (which is a function of greater wealth and a more diversified portfolio) and the greater human capital of operators of large farms may also explain why large farms have incentives or propensities to adopt new technology. Among rural sociologists, Rogers (1995) points out that, empirically, adopter category characteristics and farm size appear interrelated.

Human Capital. The ability to adapt new technologies for use on the farm clearly influences the adoption decision. Most adoption studies attempt to measure this trait through operator age, formal education, or years of farming experience (Fernandez-Cornejo et al., 1994). More years of education and/or experience is often hypothesized to increase the probability of adoption whereas increasing age reduces the probability. Factors inherent in the aging process or the lowered likelihood of payoff from a shortened planning horizon over which expected benefits can accrue would be deterrents of adoption (Barry et al., 1995; Batte and Johnson, 1993). Younger farmers tend to have more education and are often hypothesized to be more willing to innovate.

Risk and Risk Preferences. In agriculture, the notion that technological innovations are perceived to be more risky than traditional practices has received considerable support in the literature. Many researchers argue that the perception of increased risk inhibits adoption (Feder et al., 1985). When an innovation first appears, potential users are generally uncertain of its effectiveness and tend to view its use as experimental (Mansfield, 1966). Hiebert (1974) and Feder and O'Mara (1981, 1982) show that uncertainty declines with learning and experience, thus inducing more risk-averse farmers to adopt an innovation provided it is profitable. Innovators and other early adopters are believed to be more inclined to take risks than are the majority of farmers.

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While risk attitudes are often hypothesized to influence technology adoption, the use of specific risk management tools may also be associated with the adoption decision. Market and production risks faced by most producers can be managed via a variety of mechanisms, including contracting, integration, adjusting input and/or output levels, storage, hedging, diversifying, time sequencing transactions, and insurance (Robison and Barry, 1987). Contracting, while very common in fruit and vegetable production, is increasing among growers of specialty corn and soybeans, especially with the introduction of GE crops where producers need to be assured of a market (Bender and Hill, 2000; Perry et al., 1977). King (1992) points out that for processors, contracts "...help ensure predictable supplies and quality. For producers, they can offer price stability and access to specialized expertise, information and inputs (p. 1217)."

The role of risk aversion in producer behavior in the adoption of GE crops is examined by Alexander, Fernandez-Cornejo, and Goodhue (2000). They find that among corn and soybean producers, those who reduce their acreage in one GE crop are more likely to reduce their acreage in the other GE crop, indicating that producer risk preferences are independent of the crop. They also find that risk preferences, as measured by responses to survey questions, are positively and significantly related to the decision to plant GE corn. This suggests that risk and returns both support a reduction in GE corn acreage. In contrast, risk preferences do not explain the share of GE soybeans, which is consistent with the prediction that the production characteristics of GM soybeans dominate the price uncertainty. These results are consistent with risk-averse or risk-neutral producers.

Tenure. Land ownership is widely believed to encourage adoption of technologies linked to land. While several empirical studies support this hypothesis, the results are not unanimous and the subject has been widely debated (e.g., Feder et al., 1985). For example, Bultena and Hoiberg (1983) find no support for the hypothesis that land tenure had a significant influence on adoption of conservation tillage. The apparent inconsistencies in the empirical results are due to the nature of the innovation. Land ownership is likely to influence adoption if the innovation requires investments tied to the land. Presumably, tenants are less likely to adopt these types of innovations because they perceive that the benefits of adoption will not necessarily accrue to them. Because the use of bioengineered crops does not require land-tied investments, land tenure may not affect adoption of this technology.

Labor Supply. Given the high level of interdependency between the household and farm business, the combined labor supply of the operator and spouse indicates the total amount of time available for farming and nonfarming activities. Operator and/or spouse off-farm employment may constrain adoption of management-intensive technologies because it competes for farm managerial time (McNamara et al., 1991). Conversely, adoption by households with off-farm employment may be encouraged if the technology is operator labor-saving, as may be the case with GE crops.

Credit Constraints. Any fixed investment requires the use of own or borrowed capital. Hence, the adoption of a nondivisible technology, which requires a large initial investment, may be hampered by lack of borrowing capacity (El-Osta and Morehart, 1999). GE crops clearly do not fit the model of a capital-intensive technology. Consequently, a credit or capital constraint should not have an adverse impact on the adoption of GE crops.

Location Factors. Location factors—such as soil fertility, pest infestations, climate, and availability or access to information—can influence the profitability of different technologies across different farms. Heterogeneity of the resource base has been shown to influence technology adoption and profitability (Green et al., 1996; Thrikawala et al., 1999). Also, the source of vendors for technologies may vary spatially, as well as the perceived need for the technology. Dummy variables that represent location or resource variables such as region, soil type, weather, climate, availability of information, etc., are often used to control for spatial variation in adoption.

proportion of corn acres planted with Bt corn by 2.6 percent. The interpretation of the elasticity for binary variables, such as operator education, is somewhat different. For example, a 10-percent increase in the *proportion* of corn farmers pursuing education beyond high school would lead to an increase of 3.4 percent in the expected proportion of corn acres planted with herbicide-tolerant corn.

Our analysis of the factors affecting GE adoption focuses on the role of farm size. Since the adoption literature suggests that farm size is often a surrogate for other factors (e.g., wealth, access to credit—see box 2), this study attempts to control for many of these factors in order to isolate the effect of farm size on adoption.

Effect of Farm Size

Characteristics of GE crop technologies led us to expect that adoption would be invariant to farm size. GE crop technologies are embodied in the variable inputs (e.g., seeds), which are completely divisible. Thus, GE crops may be used in any amounts, unlike technologies embodied in "lumpy" inputs like tractors or other machinery, which require extensive capital investments and many acres over which the operator can spread the costs of acquisition.[10]

However, actual mean adoption rates for different farm sizes, obtained directly from 1998 USDA survey data, are not constant (fig. 7). Adoption rates appear to increase with size of operation for all the technologies, but in different patterns. For example, the adoption of herbicide-tolerant soybeans and corn was fairly stable (39-52 percent for soybeans and 6-10 percent for corn) for farms above 50 acres. In contrast, the adoption of Bt corn increased continuously with the size of the operation.

While illustrative, this comparison of means would be valid only in an ideal experimental setting where factors other than size are "controlled" by making them as similar as possible. Thus, differences in mean adoption rates cannot necessarily be attributed to size since survey results are influenced by many other

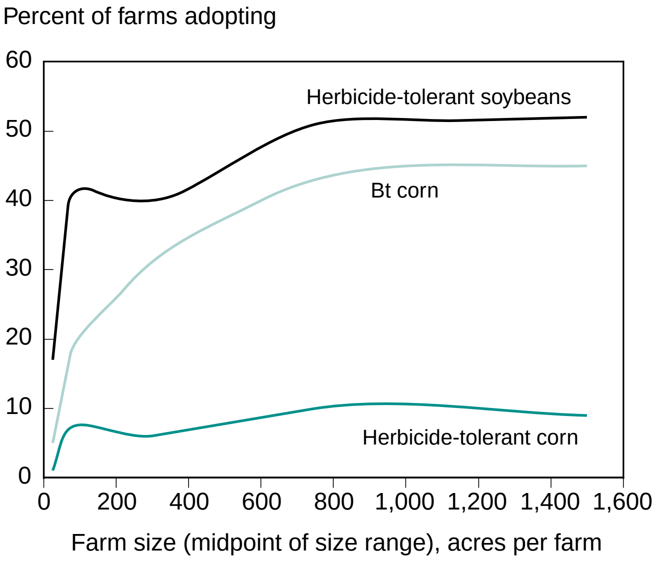
Table 3—Factors affecting the adoption of GE crops, 1998

Factor	Herbicide-tolerant soybeans	Bt corn	Herbicide-tolerant corn
		Elasticity[1]	
Education	0	0.179	0.336
Experience	0.236	0	0.453
Marginal region	-0.079	0	0
Size	0	0.258	0.279
Risk	-0.859	0	0
Limited-resource	-0.049	0	0
Contract	0.036	0.022	0
High infestation	na	0.123	na

[1] The contribution of each factor toward adoption is measured as an elasticity. The elasticity of adoption is the relative change in (the probability of) adoption relative to a small relative change in the contributing factor. An elasticity of zero indicates a statistically insignificant underlying coefficient.
na = Not applicable

Figure 7

Adoption of GE corn and soybeans (sample averages) by size of operation, 1998



Source: ARMS data.

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[10] We have avoided a discussion of the dependency of technology adoption on scale because of its technical nature and the controversy involved in its discussion. Researchers have debated whether certain technologies are scale dependent (e.g., "exhibit economies at large scales") and therefore are more likely to be adopted by larger farms (Kuchler and Offutt, 1986). The static definition of a scale-neutral technology requires that it involves an inexpensive variable-cost input, whereas a scale-biased technology "involves a fixed cost input and requires large capital investment" (p. 86) (El-Osta and Morehart, 1999). A dynamic approach is offered by Kinnucan et al. (1990), who maintain that scale dependency is determined by the pattern of adoption not by whether the cost is variable or fixed. By this definition, if early adopters "do happen to operate large farms, [the] new technology de facto is biased in favor of the large farmer, regardless of input type." Kinnucan et al. further argue that the crucial question is whether larger farmers have "natural propensities to adopt early." For them, early adoption is related to the ability of larger farm operations to assume risks and acquire information. Risk behavior and ability to process information depend, in turn, on management attitudes, skills, and experience, which may ultimately determine the decision to adopt early.

factors not controlled for, including location, access to credit, risk, wealth, other cropping practices, etc.

For these reasons, we proceed directly to the econometric results, which support the prior hypothesis of invariance to size for the adoption of herbicide-tolerant soybeans, after controlling for other factors (table 3). However, the adoption of herbicide-tolerant corn and Bt corn are positively related to farm size.[11] The different empirical results obtained for the adoption of herbicide-tolerant soybeans (invariance to farm size) and herbicide-tolerant corn (adoption positively related to farm size) from the Tobit analysis may be understood by examining their adoption rates. The 1998 adoption rate for herbicide-tolerant soybeans in the sample (34 percent of farms) implies that adoption of herbicide-tolerant soybeans has progressed past innovator and early adopter stages (fig. 6) into the realm where adopting farmers are much like the majority of farmers. On the other hand, the adoption of herbicide-tolerant corn was quite low in 1998 (5 percent of farms), implying that adoption of this technique was largely confined to innovators and other early adopters who tend to control substantial resources and are willing to take the risks.

This result is consistent with Rogers' observation that adoption is more responsive to farm size at the innovator stage and that the effect of farm size on adoption generally diminishes as diffusion increases.[12] This effect can be more closely examined by using the decomposition of the responsiveness (measured by the elasticity) of adoption with respect to size into components that reflect the behavior of users and nonusers of the technology. The decomposition of the elasticity of size for each technology (table 4) reveals that adoption of herbicide-tolerant corn by nonusers was much more responsive to changes in size than for the other technologies (0.442 percent per 1-percent increase in size).[13]

The results for Bt corn are more difficult to interpret. Bt corn was adopted by 20 percent of farms in 1998, a level inclusive of more than innovators and other early adopters (Rogers, 1995). However, unlike herbicide-tolerant soybeans, the estimated adoption elasticity of Bt corn with respect to size was positive and significant. One important difference between Bt corn and the herbicide-tolerant technologies is that Bt corn is designed to target a pest with much more spatial variation than pests targeted by the other technologies. European corn borer (ECB) infestations are quite severe in some areas and virtually nonexistent in others. Although we attempted to control for spatial variability in ECB infestations, it may be that the measured impact of farm size on Bt corn adoption was influenced by the correlation between farm size and ECB infestations. In fact, many western corn-producing States (e.g. Iowa, Nebraska) tend to have large corn farms and are also more likely to have high ECB infestations. It would have been interesting to examine if Bt corn adoption increases with size among farms with an ECB infestation above a certain threshold, but this analysis could not be conducted because of insufficient data.

Moreover, the responsiveness of the adoption to farm size was largest for the farms that had already adopted Bt corn in some of their corn acreage (in those farms, an

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[11] The analysis also shows that for Bt corn, both the linear and quadratic coefficients of the size terms are significant, the linear term positive and the quadratic term negative. This implies that in this case, there is a maximum size beyond which adoption no longer increases with increased size. The maximum, at which adoption declines as size increases, occurs at a size of 1,170 acres (which is about a fifth of the largest corn farm in the sample). The maximum does not exist for herbicide-tolerant corn because only the linear term is significant, or for herbicide-tolerant soybeans because they are invariant to size.

[12] Rogers (1995) observes that empirically, adopter category characteristics and farm size appear interrelated. He posits the following generalizations with respect to innovators and early adopters compared with other adopter categories: they are more educated; have higher social status as measured by such variables as income and wealth; have larger farms; tend to be commercial farms rather than subsistence or part-time farms; are more likely to understand and use credit; are likely to have greater association with change agents (i.e., media, consultants, extension, etc.); and have more specialized farming operations. Rogers (1995) reasons that innovators and early adopters (fig. 6): (1) need to control considerable resources to absorb possible losses from an unprofitable innovation, (2) have an ability to understand and apply complex technical language, and (3) have an ability to cope with uncertainty associated with any new innovation.

[13] According to the extension of the McDonald-Moffit decomposition for a two-limit Tobit (appendix II), three components of the elasticity can be identified. The first component indicates how responsive the probability of adoption is to changes in size. For Bt corn, with a 1-percent increase in average size, the probability of adopting Bt corn by nonusers would increase by 0.217 percent. The second component indicates how responsive the proportion of acreage under adoption by current users of the technology is to changes in size. As average size increases by 1 percent, the proportion of acres with Bt corn would increase by 0.483 percent for current adopters. The last elasticity component, unique to the two-limit Tobit, indicates how responsive the probability of having all acreage under the technology is to changes in size. If size increases by 1 percent, the probability of using Bt on all corn acreage increases by 0.74 percent.

Table 4—The size effect on adoption

Item	Herbicide-tolerant soybeans	Bt corn	Herbicide-tolerant corn
Elasticity of size (measured at the means):			
Total elasticity of adoption with respect to size-- Increase in percent of acreage under adoption for all farmers per a 1-percent increase in size	0	0.258	0.279
Decomposition of the elasticity of size			
Increase in the probability of adoption by non-adopters (in percent) per a 1-percent increase in size	0	0.217	0.442
Increase in percent of acreage under adoption for farmers that have already adopted per a 1-percent increase in size	0	0.483	0.242
Probability (in percent) of having all planted acres under adoption per a 1-percent increase in size	0	0.074	0.104
Size			
Size at which the elasticity of adoption becomes negative, 1,000 acres	na	1.170	Infinity
Largest farm in the sample, 1,000 acres	7.00	5.89	5.89

Note: An elasticity of zero indicates a statistically insignificant underlying coefficient. na = Not available.

increase in size of 1 percent led to an increase in the Bt corn acreage of 0.483 percent, table 4). Adopters of Bt corn may choose to plant Bt corn throughout the operation because ECB infestations tend to be widespread. Thus, once the decision to control for ECB is made, it is implemented across much of the operation. However, the probability that a given farm would have all their acreage under adoption was lower for Bt corn than herbicide-tolerant adopters because of refuge requirements associated with Bt corn.

To conclude, the interrelationships between the attributes of innovations and the characteristics of adopters at different stages of the diffusion process make it difficult to examine the influence of size on the adoption of innovations. Theoretically, this difficulty is inherent to the data commonly available and could be surmounted if the model included every factor that characterizes an innovator such that size effect could be totally isolated. In practice, one uses proxies for most relevant factors, such as risk, operator management skills, etc., which are limited by the quality of the data. It is doubtful that adoption patterns can be used to categorize technologies as size invariant or size dependent because such categorization depends not only on the attributes of the innovation but also on the extent of adoption and characteristics of the adopters.

Moreover, technology adoption is a dynamic process. This study attempted to measure the role of farm size in adoption at one point in time (1998) and does provide a point of reference. Comparing these results with measurements at future points in the diffusion process would further the understanding of how the characteristics of these technologies influence their adoption by farms of various sizes.

Effect of Other Factors

Adoption of all three of the GE crop technologies was positively and significantly influenced by operator's education, experience, or both (table 3). These factors may also reflect management quality in the sense that more educated or experienced operators are more likely to understand that the economic benefits of new technologies usually accrue to early adopters.[14]

The use of contracting (marketing or production) was positively associated with technology adoption in most of the models. The effect of contracting may be indicative of the greater importance placed on risk manage-

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[14] However, operator experience was not significantly associated with the adoption of Bt corn. Experience implies a better understanding of the pressures exerted by pests and the economic threshold for adoption, particularly important in the decision whether to adopt Bt corn. Thus, while operator experience may have been crucial for the adoption decision, experience had no significant association with the decision **to adopt** because experienced operators adopt (or not) if the expected benefits of adoption exceed expected costs (or not).

ment by adopting farms. Contracting locks in a commodity price or service fee and ensures a market for GE crops, lessening price and any market access risk that could result from uncertain consumer acceptance of these crops. GE crops also reduce production risks by lowering the likelihood of yield losses due to weed and insect pressure.

Location of the operation outside of the primary production area (outside the Heartland and the Mississippi Portal, appendix 2) was associated with a lower expected adoption for herbicide-tolerant soybeans. Among the farm typology variables (developed by ERS and defined in detail by Hoppe et al., 1999, 2000), only the limited-resource classification variable[15] was significant in the model for herbicide-tolerant soybeans, and these farms were less likely to adopt (as expected, given their more limited access to information and capital necessary to afford the GE technology fees). Corn borer infestation had a significant and positive influence on the expected adoption of Bt corn. Credit reserves, off-farm work, and land tenure were not significant in any of the adoption models. Compared with other agricultural innovations, such as soil conservation improvements, these factors are probably less important to the adoption of GE crops because of their unique attributes, such as low fixed costs.

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[15] Limited-resource farms are small farm operations with annual sales less than $100,000, assets less than $150,000, and household income less than $20,000.