Adoption of Agricultural Production Practices

Lessons Learned from the U.S. Department of Agriculture Area Studies Project

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1. Introduction

The U.S. agricultural sector provides an abundant and affordable supply of food and fiber. In some locations, however, farming activities are believed to have contributed to the degrading of ground and surface waters. Concern about agriculture-induced water quality problems grew during the 1980s, and several major efforts were undertaken to determine the extent of the problems, potential changes in farming practices that would avoid or mitigate such damages, and policies to effect such changes. This document reports on one of those efforts: The U.S. Department of Agriculture (USDA) Area Studies Project. This project entailed the administration of a detailed field-level survey to farmers in 12 watersheds in the United States to gather data on agricultural practices, input use, and natural resource characteristics associated with farming activities.

The objectives of this report were to use a consistent methodological approach with the full set of data to study the constraints associated with the adoption of selected farming practices that may reduce environmental damages, and to assess how adoption of those practices affected yields and chemical use. In addition, the unique sample design for the survey was used to explore the importance of field-level natural resource data for evaluating adoption at both the aggregate and watershed levels.

The development of the Area Studies Project is described briefly below. The next chapter presents the characteristics of the survey instrument and summarizes the data to show the variety of agricultural land uses, farm sizes, and resource characteristics represented by the survey. Several published studies are described that were based on the use of subsets of the Area Studies survey data. The unified econometric framework that was used to analyze the aggregate data set encompassing 10 areas,[1] and the core set of variables used for each analysis are also presented in chapter 2.

Chapters 3 through 6 present the econometric analyses of the adoption of technologies and practices within four key management categories: nutrients, pests, soil, and water. Each chapter describes survey data relevant for the category and then presents the results of the analyses of the adoption of management practices for the combined area. We used the same unified econometric framework and set of core variables described in chapter 2 for each analysis. In addition to the com-

[1] Data were not sufficient in two of the 12 study areas to provide statistically reliable estimates.

bined-areas analyses, selected areas were chosen for analysis to illustrate the difference in results between aggregate and area-specific models. The symmetry imposed on these chapters is intended to help readers focus on the practices of interest to them and to facilitate using this report to reference individual studies. For example, a reader primarily interested in pest management practices need read only chapters 1, 2, and 4. Chapter 7 describes further analyses of how adoption of specific management practices affects chemical use and crop yields. The final chapter summarizes the results of the comprehensive analysis of the Area Studies survey data and presents the strengths and weaknesses of using a field-level, watershed-based survey approach.

Background of Area Studies Project

In 1989, the President's Water Quality Initiative was started in response to public concern about agricultural chemicals in groundwater. Sediment and chemical loadings can damage environmental quality and human health. Because of the nonpoint nature of the pollution problem, it is hard to trace cause and effect. As Antle and Capalbo (1991) pointed out, "chemical use in agriculture has, over the last 50 years, been the good, the bad, and the uncertain." Studies have since shown that nutrients and sediments from agriculture are the leading source of impairment of U.S. rivers, streams, and lakes (U.S. EPA, 1995, 1998). Ribaudo (1997) presents a comprehensive summary of current water quality issues. Many of the management practices developed to reduce agricultural nonpoint source pollution were believed to be inexpensive to implement and, once implemented, would raise farmers' profits (U.S. Congress, OTA, 1995). These pollution-reducing practices were not being adopted at a rapid rate, however.

The primary objectives of the multi-agency Water Quality Initiative were to: (1) determine the nature of the relationship between agricultural activities and ground water quality, and (2) develop and induce adoption of technically and economically effective agro-chemical management and agricultural production strategies to protect ground water quality. The program was designed with the intent of meeting the objectives without burdensome regulations and without any loss of agricultural productivity and profitability (USDA, 1989). USDA developed programs of research, education, technical assistance, cost sharing, data collection, and analysis. The Economic Research Service (ERS) was given the lead responsibility and funding to build a database on agro-chemical use and associated farm practices. The three primary data efforts were: (1) the Cropping Practices Survey, which provided benchmark measurements and monitored changes of chemicals applied and cropping practices by State for six major field crops for 1990-95; (2) the Vegetable and the Fruit and Nut Chemical Use Surveys, which obtained whole farm, input use, and practice data for major specialty crops; and (3) the Area Studies Survey, which was designed to provide a link between natural resource characteristics, farm production practices, and water quality at a local level.

The Area Studies Project was based on the growing body of work showing the need to link economic models of agricultural production with models of the physical environment. Site characteristics will influence the choice of many production practices and will determine the environmental consequences of that choice (Opaluch and Segerson, 1991; Antle and Capalbo, 1991; Just and Antle, 1990). For example, soil permeability may affect a producer's choice of irrigation system and fertilizer application method. The permeability of the soil will also determine the speed and distance chemical residuals will be transported and the likelihood of their reaching an environmentally sensitive resource. When the effectiveness of practices is correlated with natural resource assets used on the farm, the spatial pattern of practice use will be determined by the distribution of those physical characteristics (Caswell, 1989, 1991). The distribution of physical characteristics will also determine the relative vulnerability of natural resources to agricultural nonpoint pollution (Shoemaker, Ervin, and Caswell, 1993). Early work on identifying groundwater resources that were potentially vulnerable to agricultural chemical degradation was published in Kellogg et al. (1992).

The two fundamental categories of site characteristics are (1) those that have impacts on a grower's choice of production practices and (2) those that will determine the impact of the production choices on environmental quality. These are not mutually exclusive sets of characteristics. For example, the organic content of the soil at a site may be a factor in a farmer's choice of tillage practice and the irrigation system that is used. The organic content will also be a factor in erosion and deep percolation of chemicals that can be affected by tillage and irrigation choices. Each site is associated with a combination of characteristics in the production-impact and environmental-impact categories.

Policy changes that affect practice adoption will alter the spatial pattern of environmental effects, so information is needed on management practices and the environmental attributes of the land in production (Antle et al., 1995). Heterogeneous land and climate conditions will determine both agricultural production and environmental impacts of policies (Just and Antle, 1990). Wu and Segerson (1995) have shown that if one uses aggregate data and ignores site characteristics in analyzing the impacts of agricultural activities on water quality, one's conclusions may be subject to five potential sources of bias. These sources can be categorized in two types: "(1) Those relating to incorrectly estimating pollution per acre, and (2) those relating to incorrectly estimating the number of polluting acres" (Wu and Segerson, 1995).

The Area Studies survey was developed to test the hypothesis that differences in productivity caused by physical characteristics of farmland will determine the distribution of adoption behavior for some agricultural practices. The production-impact component of site characteristics can be analyzed with economic models. Evaluation of the environmental-impact factors requires physical modeling of the fate and transport of residuals that result from the choices of practices and technologies. The amount of information needed to construct a fully integrated economic and physical model can be daunting, however, even for a small geographic region. Much of the early discussions about developing the Area Studies Project centered on identifying the minimum data needs to estimate the integrated model parameters.

The Area Studies Project was a collaborative effort between USDA agencies (Economic Research Service (ERS), National Agricultural Statistics Service (NASS), and the Natural Resources Conservation Service (NRCS, formerly Soil Conservation Service, SCS)). In addition, there was extensive interaction with the U.S. Geological Survey (USGS) and the U.S. Environmental Protection Agency (EPA).[2] The link between the enumerated survey data and the natural resource base came from the sampling frame, which was based on the NRCS Natural Resource Inventory (NRI) sites. Each observation was identified with a sampled NRI point that provided the physical data that represented the farm operator's resources. Many of the site's production-impact and environmental-impact characteristics are included in the NRI data base and its links.

Two pilot projects were planned to precede the Area Studies Project to test the feasibility of linking agricultural production and potential water quality effects: (1) The Cotton Water Quality Study, and (2) the Delmarva Area Study.[3] The 1990 Cotton Water Quality pilot survey was designed to supplement the Cropping Practices Survey with information on soil resources associated with each surveyed field. The project was meant to provide sufficient information to assess the scope of cotton production by land characteristics most vulnerable to groundwater contamination. The data gathered included soil loss potential, slope, soil texture, proximity of field to water body, agricultural practices used, fertilizer, insecticide, fungicide, defoliant, and growth-regulator use rates.[4] Results from the Cotton Water Quality pilot survey are reported in Crutchfield et al. (1992).

The 1990 Delmarva Area Study data were obtained from a special NASS pilot survey that was designed to interface with an ongoing groundwater study by USGS in the region.[5] The watershed is heavily agricultural, and there is a strong demand for high-quality water resources. The basic survey instrument design used in the Area Studies Project was tested and modified through the Delmarva effort. The survey originally was designed to gather sufficient data to develop a multi-output/input production function to capture the output/input substitution possibilities associated with natural resource assets. This information then would be used within a policy simulation model for each selected watershed. Data needs were prioritized after it became clear that the survey instrument as initially proposed was both long and complex. The highest priority information was crop-specific data on chemical use and practices. The second highest priority need was for economic information related primarily to crop production. Lower priorities were assigned for details about government commodity program participation, off-farm income, and livestock waste disposal. All priorities were included in the Delmarva pilot survey, but it was found that data from many of the economic questions were not statistically reliable.

[2] Bill Wilbur (USGS) and Peter Kuch (EPA) worked closely with ERS staff throughout the Area Studies Project development.

[3] A Florida Area Study pilot was also planned in collaboration with the University of Florida, but funding was insufficient to field three special surveys.

[4] Unfortunately, herbicide use rate data were not gathered due to problems in scheduling interviews.

[5] The Delmarva Peninsula lies between the Chesapeake and Delaware Bays and is so named because it encompasses areas governed by Delaware, Maryland, and Virginia.

In 1991, the Delmarva Area Study pilot project experience and other elements of the ERS Water Quality research program were presented to an external review team made up of university economists.[6] Input from this group was used to make mid-course corrections in program design, particularly with respect to the Area Studies survey development.

It had been envisioned initially that the number of sites surveyed through the Area Studies data collection program would be sufficient to provide the coverage needed to make a national assessment of the extent of agriculture's role in water quality problems. The review team strongly urged that the intensity of sampling at the watershed level not be compromised by attempts to broaden the number of sites surveyed. They advised that the Area Studies Project should focus on understanding economic behavior in relation to natural resource conditions. A criterion for site selection could be the inclusion of representative conditions that characterize U.S. agriculture, but not to claim that it was a national sample. The individual investigations of watersheds and comparisons between them were thought to be the most valuable uses of the survey design that sampled within "environmentally relevant," rather than political, boundaries. These boundaries would correspond to those used by USGS for sampling and assessing water quality conditions. The Cropping Practices Survey and other ERS/NASS surveys could be used for national, State, or regional reporting of crop production or technology use. The Area Studies Project would report information at the watershed level only and primarily be used for research into the link between the adoption of agricultural practices and the natural resource base.

Theory of Adoption Behavior

There is an extensive body of literature on the economic theory of technology adoption. We will review only a small portion of that work. The understanding of the driving forces of adoption is important for the development of pollution-reducing technologies because the effectiveness of the technology will depend on where and when it is used (Stoneman and David, 1986). For many years, there were separate adoption theories in education, sociology, anthropology, medicine, rural sociology, marketing, and industry. Much of it was based on "contagion" theory, which associated the probability of adoption with the proximity of a prior adopter. Griliches (1957), in his pathbreaking work on hybrid corn, showed that profitability was the largest determinant of adoption. Rogers (1983) agreed that the attributes of the technology were important, but that profitability was only one component. He stated that the "five attributes of innovations are (1) relative advantage, (2) compatibility, (3) complexity, (4) trialability, and (5) observability" (Rogers, 1983, p. 211). Profitability in its narrowest sense is only a factor within the first category. However, the other categories can all represent "costs" to a potential adopter because they encompass new information and adjustments that must be made.

The adoption of technology for natural resource management and conservation, such as soil conservation, integrated pest management, soil nutrient testing, and irrigation management, are considered apart from the use of conventional inputs such as agricultural fertilizers and chemicals. While decisions on the amount of conventional inputs to apply are made on a seasonal or annual basis, the adoption of new technology represents a significant shift in a farmer's production strategy. The decision to adopt new technology is analogous to an investment decision. The decision may involve substantial initial fixed costs, while the benefits accrue over time. The initial costs may include the purchase of new equipment and of learning the best techniques for managing the technology on the farm. A producer may perceive the nonmonetary costs of change to be very high.

An individual's assessment of the new technology is subjective and may change over time as a farmer learns more about the technology from neighbors who have already adopted it, the extension service, or the media. When a technology first becomes available, uncertainty about its performance under local conditions is often high. Significant adaptation of the technology may be necessary before it performs well in the local production environment. Over time, as some farmers in an area adopt and gain experience with the new technology, the uncertainty and cost of adoption fall. Some farmers may fail to adopt the technology altogether if they determine that it simply does not perform well under their resource conditions, or if the size or type of their farm operation is not suited to the technology in question (Griliches, 1957).

[6] Members of the external review team were: William Boggess, Susan Capalbo, Otto Doering, Richard Howitt, Tim Phipps, Tony Prato, and Kathleen Segerson. The team met with ERS staff at Airlie House in Virginia, January 22-23, 1991. Written review comments were submitted in March 1991.

A new technology or innovation will change the marginal rate of substitution between inputs in a production process. Some changes may be perceived as large by a potential adopter. Early studies of adoption were based on the assumption that people were resistant to change and that resistance had to be overcome (Nowak, 1984). There is a distinct difference, however, between a producer who is unable to adopt versus one who is unwilling to adopt. Nowak (1992) summarized these two types of barriers to adoption:

Inability to adopt: (1) Information lacking or scarce; (2) Costs of obtaining information too high; (3) Complexity of the system too great; (4) Too expensive; (5) Labor requirements excessive; (6) Planning horizon too short (benefits too far in the future); (7) Limited availability and accessibility of supporting resources; (8) Inadequate managerial skill; and (9) Little or no control over the adoption decision.

Unwillingness to adopt: (1) Information conflicts or inconsistency; (2) Poor applicability and relevance of information; (3) Conflicts between current production goals and the new technology; (4) Ignorance on the part of the farmer or promoter of the technology; (5) Inappropriate for the physical setting; (6) Increased risk of negative outcomes; and (7) Belief in traditional practices.

Many of the distinctions made between inability and unwillingness to adopt are based on relative judgments (i.e., too high, too short, inadequate) and would be difficult to test empirically. Another way to differentiate nonadopters is to characterize them as (1) those for whom adoption would not be more profitable than continuing with current practices, and (2) those for whom adoption would be more profitable but who choose not to switch technologies due to other barriers. Policies designed to encourage adoption would need to be targeted differently for these two groups.

Many of the conservation or chemical-reducing technologies included in the Area Studies analysis can be classed as "preventive innovations" in that they facilitate the adopter's avoiding some unwanted future event such as groundwater contamination or loss of productive soils. As Rogers (1983) points out, preventive innovations have a low rate of adoption because it is hard to demonstrate the advantages of adoption since those benefits occur only at some future, unknown time. Pample and van Es (1977) distinguished between practices designed to protect natural resources and those designed primarily to increase farm profits. They conclude that the "means and goals of the two types of practices appear sufficiently different to possibly result in different adoption behaviors" (p. 58).

The current economic theory of adoption is based on the assumption that the potential adopter makes a choice based on the maximization of expected utility subject to prices, policies, personal characteristics, and natural resource assets. A discrete choice of technology is made that leads to a level of input use and profit. If the benefits associated with the use of a conservation technology accrue primarily beyond the farm, producers would not be expected to include those benefits in their decision to adopt the technology. Many of the recommended practices are designed to reduce off-site environmental impacts rather than to increase on-site productivity. The total benefits of switching to these technologies may outweigh the costs by a large margin, but if those gains are not realized by the farmer who bears the costs, the voluntary adoption of preferred technologies may not occur.

Since neither farms nor farmers are identical, there will be differences in whether a particular technology is adopted and when. Farmers will differ in their ability to understand and adapt to innovative methods, and in the quality of the land they control. The farmer is aware of these factors and uses that knowledge to assess the expected gain of adoption. The distribution of the underlying heterogeneous factors will determine the pattern of practice adoption. When one of the heterogeneous factors is associated with natural resource characteristics, the adoption pattern can be defined spatially.

The effectiveness of policies designed to improve water quality or other environmental assets through promoting the adoption of conservation technologies and management strategies will depend on an understanding of how farmers choose their production practices. The Area Studies Project was designed to characterize the extent of adoption of nutrient, pest, soil, and water management practices and to assess the factors that affect adoption for a wide range of management strategies across diverse natural resource regions.

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