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The Adoption and Diffusion of Level Fields and Basins

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Strategic investments in agriculture often are lumpy and irreversible, with significant impacts on operating and fixed costs. Leveling cotton fields to zero slope in central Arizona is a strategic decision made by relatively younger farmers who are farming fine-textured soils in irrigation districts with higher expected water costs. The diffusion of the technology across the region between 1968–89 appears to be both a function of institutional changes (e.g., the Groundwater Management Act of 1980, the Central Arizona Project) and the long-run expected price changes induced by these new policies.

Key words: laser leveling, technology adoption and diffusion, water conservation

Introduction

Technological change has long been identified as a driving force behind the changing structure and performance of the U.S. agricultural sector. From the adoption of tractor power and hybrid seeds, fertilizers, and pesticides to the potential reliance on biotechnology to ensure higher yields and lower costs, agricultural producers have been induced to adopt new production practices by the economic realities of the market. Most of these new agricultural technologies can be divided into two categories: operating and long term. Operating innovations impact most directly on annual variable costs, and possibly production levels. Their use requires few to only moderate management changes, and the decision to use the new technology is reversible. Improved seed varieties, new pesticides, and livestock implants and vaccinations are several examples of operating innovations.

In the case of long-term technologies, the producer faces a decision which is costly to reverse and requires planning. These investments change both variable and fixed costs, often require equity and/or debt financing, may increase the scale of the production unit, and can require more intense management to ensure favorable economic returns. Pindyck and others argue that favorable, but irreversible, technology decisions require positive net present values to reflect the opportunity cost to the firm of keeping its investment options open. Examples of long-term, irreversible investments include the

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purchase of new field equipment and machinery, farm expansion, and the adoption of some new irrigation technologies.

The adoption of new agricultural technologies has been reviewed thoroughly by several analysts (e.g., Rogers; Feder, Just, and Zilberman). Starting with the work on hybrid seed corn, early researchers discovered that adoption of agricultural innovations was a function of the quality and quantity of information available to the decision maker and dependent on personal, first-hand experience with the technology. Adopters were better educated, had higher social participation rates, farmed larger acreages, and had higher incomes than the nonadopters. Griliches (1957, 1960) introduced expected profitability as a critical variable in the adoption process. Griliches found that the aggregate adoption or diffusion of hybrid seed corn followed an S-shaped logistic curve, with the adoption of the innovation being more rapid in areas which profited the most from the new technology (e.g., Iowa versus Georgia). Feder and others developed formal decision models which characterize the adoption process under uncertainty. Farm size, risk attitudes, government policies (e.g., subsidies, taxes, extension programs), and the costs of acquiring information about the new technology were found to be important in determining the probability of adoption. Previous empirical research includes work regarding the adoption of minimum or conservation tillage practices (Lee and Stewart), studies focusing on new irrigation technologies (Caswell and Zilberman; Lichtenberg; Negri and Brooks; and Green et al.), analysis concerning the adoption of microcomputers by California farmers (Putler and Zilberman), and investigation of technologies adopted by dairy farmers (Zepeda).

The diffusion literature has been analytically summarized by Davies; Sahal; and Thirtle and Ruttan. These authors argue that logistic-like diffusion curves mask the multidimensional process reflected in aggregate adoption rates; i.e., diffusion is not just a matter of time, but the result of an interaction between supply and demand factors. Individual firms respond differently to new technologies due to: (*a*) their capacity to process information, (*b*) their risk preferences and perceptions, and (*c*) the degree of technical compatibility between the innovation and the firm's existing production processes. This literature also notes that the diffusion process is influenced by factors exogenous to the firm such as market pressures, government policy, and the general economic environment. Specifically, long-run price expectations, perhaps influenced more by changing government policies than by observable market forces, trigger strategic investments in new technologies by modifying the present value of an expected net income stream. Conceptual support outside of agriculture for the hypothesis that institutional changes can drive investments can be found in Nelson and Winter, and in David, while Hannon and McDowell provide empirical evidence for the important role of institutions in technology diffusion.

Most of the agricultural economics literature is focused on the adoption of operating technologies, and the empirical evidence is predominantly from less industrialized countries. Limited empirical evidence exists on recent farm-level adoption decisions of long-term technologies, and even less on the diffusion of new, irreversible technologies across a geographic area in the United States. Our study reports the results of an investigation into the factors influencing both the adoption and diffusion of level fields and basins in a cotton-growing region of central Arizona from 1968 through 1989. Our results lead us to hypothesize that some irreversible agricultural investments are induced by expected permanent changes in the business environment, often as a result

of new government policies. The study is organized as follows. The institutional setting describes the unique, state-specific policy environment affecting farmers in the region. The setting is followed by a description of the technology adopted, the conceptual guide, data and empirical models, results, discussion, and a postscript.

Institutional Setting

Under pressure from the federal government, the Arizona state legislature passed the 1980 Groundwater Management Act (GMA) in order to regulate the use of ground water in six areas of the state and ensure political support for continued federal funding of the Central Arizona Project (CAP).[1] Active Management Areas (AMAs) were established in three important agricultural/urban areas where a long history of ground water overdraft (nearly 2 million acre-feet per year) threatened the long-term viability of farming and urban expansion.[2] With the GMA, water use is regulated through a series of management plans which gradually enforce more restrictive water conservation practices in both agricultural and urban areas. Safe yield or zero overdraft in 2025 is the legislated goal in the Phoenix, Prescott, and Tucson AMAs. The stated goal for the Pinal AMA, an agriculturally dependent region and the focus of this study, is to "preserve existing agricultural economies in the Active Management Area for as long as feasible, consistent with the necessity to preserve future water supplies for non-irrigation uses" [Arizona Department of Water Resources (ADWR), p. 35].

The institutional vise for tightening agricultural water management practices in the AMAs is the ADWR-determined irrigation efficiency. Agricultural producers are assigned an annual ground water allotment (*GWA*) which represents the amount of water the grower can obtain from the farm's wells, from surface supplies (e.g., CAP water), or a combination of ground and surface sources during the year, where:

$$GWA = W * \bar{L}, \tag{1}$$

$$W = (I/E), \tag{2}$$

and

$$E = CWR/w. \tag{3}$$

From (1)–(3) above, W is the irrigation water duty, and $\bar{L}$ is the highest number of acres in the farm irrigated during the period January 1, 1975 to January 1, 1980. The average annual irrigation requirement per acre for crops grown on the farm during this period is denoted by I. E represents the assigned irrigation efficiency, where CWR is the crop water requirement and w is the actual volume of water applied. By increasing E every 10 years, the ADWR hopes to induce farmers to adopt water-conserving irrigation

[1] The Central Arizona Project (CAP) is a Bureau of Reclamation-constructed aqueduct which is delivering Colorado River water to the urban and agricultural areas in central Arizona. CAP water, roughly 1.4 million acre-feet per year, will replace two-thirds of ground water overdraft in the target region. See Wilson (1992) for a farm-level economic analysis of this program.

[2] The Phoenix, Tucson, and Pinal AMAs are considered important, both in an urban and agricultural sense. The Prescott AMA is primarily an urban area.

technologies which will assist the AMA in reaching its legislated goals. Actual water use is measured by flow meters on all wells and irrigation district-managed turnouts, and is monitored by ADWR staff. If growers use less than the *GWA*, they are allowed to bank the difference in a flexibility account and borrow from the account in following years. Positive water balances in flexibility accounts have grown in recent years due to high participation rates in federal commodity programs and other economic forces (e.g., credit constraints) which reduce planted acreage.

Water duty (W) was set by the ADWR at 5.05 acre-feet per acre per year for the first management period, 1980–90. Assigned irrigation efficiencies (E) ranged from 55–65%, thereby inducing limited conservation efforts on the part of the growers because the currently used graded furrow irrigation technology could meet this efficiency target. The second management plan, covering the last decade of this century, mandated an average water duty by the year 2000 of approximately four acre-feet per acre per year. This goal would be accomplished by incrementally raising E to 75–85% over this period. Conventionally managed graded furrow irrigation systems would struggle to meet these new efficiency requirements. Therefore, the ADWR encouraged growers to adopt modified-slope, dead-level furrow or basin, or drip systems.

The Pinal AMA, the focus of this study, is a 4,000 square mile agricultural region with nearly 65,000 inhabitants. Ground water overdraft was estimated at 949,000 acre-feet annually in the 1980s. Average annual water use during this decade was 5.80 acre-feet per acre, with cotton (both upland and Pima), alfalfa, wheat, barley, and winter vegetables being the principal crops. Prior to 1980, virtually all the acreage in the Pinal AMA was irrigated using graded (i.e., greater than 0.2 foot fall over a one-quarter mile irrigation run) furrows or basins.

Four irrigation districts manage water flows in the Pinal AMA: San Carlos, HoHoKam, Maricopa-Stanfield, and Central Arizona. The San Carlos District was established in the 1920s to deliver a mixture of ground and surface water to 100,000 acres in central Arizona. The latter three districts were formally established in the 1980s to contract for and deliver CAP water through newly constructed distribution systems to agricultural lands in the Pinal AMA. Large irrigation heads of 3,000–5,000 gallons per minute could be delivered to the farm gate through these systems facilitating the use of dead-level, zero-slope fields.

The Technology

Dead-level fields and basins became technologically and economically feasible with the development of laser-leveling technology (Erie and Dedrick). Prior to laser technology, land was leveled to the desired grade by surveying and staking fields to show the equipment operator where cuts and fills were to be made. Achieving the desired grade was dependent on the skill of the dragscraper operator, and high and low spots often remained in many fields. Initially used by the Natural Resources Conservation Service (NRCS) (formerly the Soil Conservation Service) in the Midwest during the early 1970s to lay drainage tiles, laser-leveling methods were first implemented in Arizona in 1975. Introduction of laser technology was induced by Public Law 93-320, passed in 1974, which guaranteed reduced salinity levels for Colorado River water crossing the U.S.-Mexico border. Reduced water use in, and thereby reduced drainage from, the Wellton-

Mohawk region of Yuma County became a partial means for meeting the requirements of this international agreement.[3] Through a federally supported cost-share program, with the government paying 75% of the land preparation costs, 50,000 acres of cropland were leveled to zero slope over a four-year period using laser technology.

Briefly, laser leveling centers on a laser beam-emitting tripod set up in the field (Hinz and Halderman). A receiver attached to the earthmoving equipment lowers or raises the dragscraper blade on a continuous basis. Operator error is minimized and the leveling process is expedited relative to conventional methods. Fields can be precisely dead-leveled, which is defined by the NRCS as a slope of less than 0.2 feet over a one-quarter mile irrigation run. Dead-leveled or zero-slope fields with improved irrigation management reduce deep percolation losses, facilitate the management of larger irrigation heads, and improve irrigation uniformities, thereby increasing the probability of higher crop yields and potentially reduced irrigation labor (Warrick and Yates).

A Conceptual Guide

The decision-making environment of the grower can be approximated by a mean-variance model used by Feder and Slade and discussed in detail by Robison and Barry (pp. 284–93). While not formally estimated in our analysis, this framework captures the decision-making environment and provides a guide for interpreting the statistical results. Suppose the new water-conserving technology and the conventional system are represented by scale-neutral per acre production functions, $f(w_f)$ and $g(w_g)$, respectively, where $f', g' > 0$, and $f'', g'' < 0$, and w is water applied per acre [equation (3)]. For simplicity, assume the grower produces only one crop (y) which is sold at price p, where the yield per acre associated with the conventional technology (g) is known, but where $y_f = f(w_f) + \varepsilon$, and $\varepsilon \sim N(0, \sigma_\varepsilon^2)$. The decision maker must allocate the two technologies between the total irrigated area, $\bar{L}$. Finally, assume that the decision maker overestimates σ_ε^2 by the factor $(1 + \theta)$ due to inadequate information and/or a personal hesitance to adopt new production practices (note that $\theta > 0$).

The resulting certainty equivalent, mean-variance model can be written as:

$$\max_{w,L} \pi_{ce} = p\left[Lf(w_f) + (\bar{L} - L)g(w_g)\right] - p_L L - p_w\left[Lw_f + (\bar{L} - L)w_g\right] - \frac{\lambda}{2} p^2 L^2 (1 + \theta)\sigma_\varepsilon^2, \tag{4}$$

where L is the land area allocated to the new technology at price p_L, and p_w is price of water. The Arrow-Pratt risk-aversion coefficient, λ, which is assumed to be greater than zero, demonstrates decreasing absolute risk aversion, $\partial\lambda/\partial\pi_{ce} < 0$, and contains the arguments of all the parameters which locate the EV frontier—in this case, $\lambda = \lambda(p, p_w, p_L, \bar{L}, \sigma_\varepsilon^2)$. The first-order conditions for optimal water use equate the land-weighted returns above variable costs for the two technologies, $L(pf' - p_w) = [\bar{L} - L](pg' - p_w)$. The nature of the production functions guarantees the second-order conditions for exogenously determined output prices.

[3] The Wellton-Mohawk Irrigation District is outside of any AMA.

The grower must optimally allocate the fixed resource, $\bar{L}$, between a risky technology and a comparatively safe alternative. By taking the derivative of (4) with respect to L, the optimal acreage devoted to the new water-conserving technology is:

$$L^* = \frac{p[f(w_f) - g(w_g)] - p_L + p_w(w_g - w_f)}{\lambda p^2(1 + \theta)\sigma_\varepsilon^2} \quad \text{for } 0 \le L \le \bar{L}. \tag{5}$$

The quadratic nature of the risk factor in equation (4) guarantees that L^* is an optimal value. The numerator in (5) reflects the importance of the difference in expected per acre yield, the per acre investment cost of the new technology, and the per acre value of the water savings. These relative profitability factors have been the critical components of earlier analyses of the economics of water-conserving technologies (Daubert and Ayer; Wilson, Ayer, and Snider; Wilson, Coupal, and Hart; Coupal and Wilson). Yet the denominator of this optimal condition argues for the consideration of risk preferences, information, and variability associated with the new technology as important considerations as well. Further examination of (5) yields the following ceteris paribus assertions: the impact of p and p_w on L^* is uncertain (dL^*/dp, $dL^*/dp_w \gtrless 0$);[4] acreage devoted to the new technology will increase with a decline in the investment cost associated with the water-conserving system ($dL^*/dp_L < 0$); and better information and a reduction in variability encourage the adoption of water-conserving irrigation technologies ($dL^*/d\theta$, $dL^*/d\sigma_\varepsilon^2 < 0$). In a non-ceteris paribus world, these economic relationships interact to facilitate, or constrain, the diffusion of the technology across the region.

Data Acquisition, Data Description, and Empirical Models

With the assistance of Arizona Department of Water Resources personnel, a stratified random sample of farming operations in the Pinal AMA was taken in 1989 using ADWR records of irrigation grandfathered rights (Snedecor and Cochran, pp. 520–26). Farms were stratified two ways: by number of water duty acres ($\bar{L}$) and by area of similar farming conditions. Farms ranged in size from 100–199, 200–499, 500–999, and 1,000+ acres. Based on discussion with ADWR staff, farms with fewer than 100 acres were not included, because most of this land is either leased by larger growers and would be accounted for in the sample, or many of these small operations are hobby farms or ranches and do not produce commercially marketed crops. Criteria for selecting areas of similar farming conditions included the cost of irrigation water, soil type, present type of irrigation systems, and the cropping pattern. Maricopa-Stanfield (MS), Florence-Coolidge-Casa Grande (FCCG), and Central Arizona (CA) were selected as the three areas of similar farming practices or conditions. The FCCG area includes the San Carlos and HoHoKam irrigation districts, and the MS and CA areas correspond to the irrigation districts described earlier. One hundred farms were sampled from a population of 558 farm units that met these criteria, producing a confidence interval of ±5% for the estimate of dead-leveled acreage.

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[4] Caswell and Zilberman suggest that as p_w and p increase, then there will be an increase in the adoption of new technology. Our model implies that this adoption may occur, but not without favorable certain returns to the new irrigation system.

A telephone survey instrument was developed in cooperation with NRCS and ADWR technical personnel. A pretest of this questionnaire revealed the difficulty of gathering pumping lift, income, leveling cost, and net worth information in an accurate and timely manner from growers. The questionnaire was simplified and pretested again with greater success.[5] Telephone surveys were conducted from July–October 1989. Complete information was gathered for 91 farms. Farmers answered questions from recall and from written records when they were available. Soil characteristics were developed from map records at the Pinal County NRCS office.

A straightforward logit model was used to analyze the decision to adopt or not adopt dead-leveled fields and basins. The adoption model is specified as:

$$P_i = \frac{1}{1 + e^{-Z_i}} = \frac{1}{1 + e^{-(\alpha + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_n X_n)}}, \tag{6}$$

where P_i is the probability that the grower will laser-level his/her fields, and Z_i is a weighted sum of a vector of socioeconomic and physical variables or factors ($\mathbf{X}_i$) which are hypothesized to influence the adoption decision. Producers were asked how many acres, if any, were dead-leveled annually from 1969–89. To facilitate the analysis, adoption for a farm unit was defined as follows: at least 10% of the acres of the surveyed farm were dead-leveled prior to 1989, or less than 10% for growers initially adopting after 1986. Nonadopters were defined as farms without initial adoption occurring from 1969–86, and less than 10% of the acreage dead-leveled. This latter category included producers who experimented with dead-level fields on small acreages (10–50 acres) and failed to continue their leveling activities.

Actual age (*AGE*) of the decision maker was hypothesized to have a negative relationship to the probability of adopting. The literature has shown that older farmers are less likely to adopt a new technology during its early introductory stage. Education (*EDUC*) was measured by a qualitative variable with a value of one for college graduates and zero for all other growers. A positive relationship between education and a favorable adoption decision was hypothesized due to the relatively more educated respondent's ability to gather, assimilate, and analyze information. Ownership (*OWN*) also was measured as a dummy variable with a unitary value for growers reporting an ownership interest in the farm unit, and zero for farms that were leased from the state, individuals, or estates and trusts. Historically, private ownership of the land resource has been positively correlated with the early adoption of new, relatively more profitable agricultural technologies.

Five physical or locational variables were included in the logit adoption model: (*a*) total acres farmed by the respondent, (*b*) size of the surveyed farm unit, (*c*) available water-holding capacity for the farm, (*d*) soil water intake rate for the farm, and (*e*) the geographic region of similar farming conditions as classified by ADWR. The total acres farmed by the respondent (*TOTACRES*) was chosen to serve as a proxy variable for the net worth or income of the respondent, since this latter information was not available. Many respondents in the sample farmed multiple farm units as recorded by the Farm Service Agency and ADWR. It was hypothesized that those growers with more acres

[5] A copy of this final questionnaire is available from the authors on request.

would be more likely to have the financial resources to make an early decision to invest in dead-level fields. Surveyed farm size (*SIZE*) measures the irrigated acres of the single farm unit. As with *TOTACRES*, the relationship between this size variable and the adoption decision was expected to be positive. Weighted average available water-holding capacity (*AWC*) and soil water intake rate (*INTAKE*) for each farm unit were obtained from NRCS records and soil maps. *AWC* is measured in inches, and *INTAKE* in inches per hour. Available water-holding capacity has been used in previous studies to explain the probability of adoption (e.g., Lichtenberg). Jensen reported that soil intake rate or infiltration also is a critical variable in determining the appropriateness and efficiency of an irrigation system. Since *AWC* and *INTAKE* are strongly negatively correlated, the composite variable *SOIL* was formed as the ratio of *AWC* to *INTAKE*. Previous empirical evidence would indicate that *AWC* and *SOIL* should have a negative impact on the probability of adopting modern irrigation technologies, while *INTAKE*'s influence should be positive.

Finally, the location of the farm in the AMA was denoted by qualitative variables (*MS* for Maricopa-Stanfield, and *FCCG* for Florence-Coolidge-Casa Grande) representing two irrigation districts, with Central Arizona (*CA*) to compare against. As noted earlier, these ADWR areas of similar farming conditions are differentiated by electrical rates, ground water pumping lifts, and the availability of lower cost, federally managed surface water. These differences are discussed further in the results section.

Because individual farm-level measures of profitability were beyond the scope of this research, the chosen explanatory variables may indirectly relate to the denominator in equation (5). Some insights concerning the relationship between risk preferences (λ) and the adoption decision are captured by the coefficients on *TOTACRES*, *SIZE*, and *OWN*. The results for *AGE* and *EDUC* should clarify the relationship associated with the decision maker's risk preferences, planning horizon, information processing capabilities (θ), and the adoption decision. The variability in yields associated with the new technology (σ_ε^2) is captured in the empirical model by *AWC*, *INTAKE*, *SOIL*, and the location variables (*MS*, *FCCG*, and *CA*).

Previous nonfarm-level research has indicated the importance of the soil endowment in adoption decisions (Caswell and Zilberman). Our research represents a farm-level test of these earlier hypotheses which were generated by simulation or aggregate economic analysis. The *AWC*, *INTAKE*, and *SOIL* variables serve as proxies for expected yield differences and the value of water savings, $P_w(w_g - w_f)$. The relative profitability of the water-conserving technology as an initial condition in the adoption process is measured partially by the physical properties of the soil. Farms with higher *AWC*, lower *INTAKE*, and higher *SOIL* measures can irrigate more efficiently in both a quantity (i.e., use less water) and quality (i.e., improved timeliness) sense due to their natural resource endowment, thereby reducing water costs and increasing yields on a comparative basis.

The diffusion period selected for level furrow or basin systems in the Pinal AMA was 1968–89. Although laser-leveling technology was not used in Arizona until 1975, the 1968–75 period was included because several growers reported leveling their fields to zero slope with conventional techniques as energy prices increased in the early 1970s. The standard S-shaped logistic curve was chosen to trace the diffusion path of laser-leveled fields:

Table 1. Selected Summary Statistics for Surveyed Farms

	REGION Mean / (Standard Deviation)			
Variables	MS	FCCG	CA	Total
Nonadopters:	**(n = 6)**	**(n = 24)**	**(n = 13)**	**(n = 43)**
AGE (years)	58	52	57	55
	(18)	(13)	(15)	(14)
AWC (inches)	1.890	1.891	1.817	1.869
	(0.275)	(0.260)	(0.296)	(0.295)
SIZE (acres)	779	270	543	424
	(898)	(174)	(413)	(444)
TOTACRES (acres)	2,009	708	1,421	1,105
	(1,330)	(280)	(1,231)	(961)
Adopters:	**(n = 22)**	**(n = 17)**	**(n = 9)**	**(n = 48)**
AGE (years)	51	47	46	49
	(11)	(9)	(10)	(10)
AWC (inches)	1.960	1.879	1.963	1.931
	(0.296)	(0.268)	(0.364)	(0.292)
SIZE (acres)	466	463	500	471
	(276)	(419)	(330)	(336)
TOTACRES (acres)	1,052	1,101	1,334	1,122
	(511)	(973)	(763)	(741)

$$Z_t = \frac{K}{1 + e^{-(b_0 + b_1 t)}}, \tag{7}$$

where Z_t is the cumulative number of leveled acres in year t, K is the ceiling of potential leveled acres, b_1 is the rate or speed of diffusion, and b_0 is a constant term. K can be adjusted to estimate different diffusion rates.

Results and Discussion

The Adoption Decision

Level fields and basins were adopted on 48 farms during the study period (table 1). Overall, adopters were younger growers farming finer-textured soils on slightly larger farms. A higher percentage of leveling to zero slope occurred in the Maricopa-Stanfield (*MS*) area, followed by Central Arizona (*CA*) and Florence-Coolidge-Casa Grande (*FCCG*). Intra- and inter-region comparisons indicate that only *AGE* clearly differentiates between the adopters and nonadopters. On average, the respondents farmed approximately three times more acres (*TOTACRES*) than were represented in the sampled farm unit (*SIZE*).

Two logit regression models were used to describe the adoption decision during the 1968–89 period—the first model using all the previously defined explanatory variables, and the second incorporating two composite variables (*SOIL* and *SIZEADJ* = *SIZE/TOTACRES*) as substitutes for four factors (table 2). Both models correctly predict adoption or nonadoption in seven out of ten cases. In both models, *AGE* is statistically significant in explaining the probability of adoption. Younger growers have a longer planning horizon and enjoy the rewards of land-augmenting technologies as they accrue over time. These individuals are more likely to adopt a risky technology which requires some "learning by doing" before the full benefits are realized. Relatively older farmers may be less willing to change irrigation technologies because they are comfortable, in a technology sense, with a tried-and-true water application method. During the interviews, several relatively older farmers expressed their difficulty in rationalizing a strategic investment like laser leveling when they had only five to ten years of active farming remaining before retirement. A younger family member was not active in these farming operations.

A college education (*EDUC*) positively influences the adoption decision, but does not clearly differentiate adopters from nonadopters. This result may be explained by the high education level of most of the respondents, with all but two growers having a high school education and 80% of the farmers reporting some formal education beyond high school. An ownership interest (*OWN*) in the farm positively influences the adoption decision and is significant at the 10% level in both models (table 2). A possible explanation for some statistical weakness of this variable is the long-term nature of leasing arrangements in the Pinal AMA. Private and state leases often are written for up to five years or longer, with provisions for renewals if the grower meets the conditions specified in the lease agreement. In many cases strategic, irreversible investments made by the lessee are protected under the lease. Upon cancellation of the lease prior to the expiration date, the lessor would have to reimburse the lessee for the present value of all capital improvements made to the property. Therefore, under these institutional conditions, the grower may not be deterred from making land-augmenting investments on leased property.

Level field and basin irrigation technology is more likely adopted on larger farm units which represent the majority of the grower's total farmed acreage. This result evolves from an examination of the results for *TOTACRES* and *SIZE* in Model 1, and *SIZEADJ* in Model 2 (table 2). The total acres farmed in Model 1 (a proxy variable for net worth and income) has a negative sign, while surveyed farm size has the hypothesized positive coefficient; however, neither coefficient is statistically significant. The insignificance of these variables was surprising and may be related to fragmentation of farms or a result of institutional incentives such as government commodity programs, Bureau of Reclamation rules and regulations, and federal tax laws. Some growers operate one or two relatively large farms (400–900 total acres). Other growers farm three to six smaller farm units but more total acreage (1,000–4,000 total acres). These multiple farm units are noncontinuous and located throughout the AMA. The statistical results indicate that there may be inducements to innovate when fewer management units are involved in the total farming operation. The positive sign and higher t-value on *SIZEADJ* in Model 2 lends some support to this claim, as does the high marginal effect (0.161) of operating a continuous farming unit. This hypothesis requires further testing in other farming regions.

Table 2. Logit Regression Results for the Level Field and Basin Adoption Decision

Explanatory Variables	Model 1 $\hat{\beta}_i$ (Std. Error)	Model 1 Means of Estimated Marginal Effects	Model 2 $\hat{\beta}_i$ (Std. Error)	Model 2 Means of Estimated Marginal Effects
Constant	-0.585 (3.067)		0.989 (1.288)	
AGE	-0.057** (0.023)	-0.011	-0.058** (0.023)	-0.011
EDUC	0.407 (0.561)	0.039	0.629 (0.496)	0.060
OWN	0.769* (0.561)	0.063	0.679* (0.524)	0.057
TOTACRES	-0.0002 (0.0003)	-0.00003		
SIZE	0.0002 (0.0007)	0.00005		
AWC	1.443 (1.381)	0.274		
INTAKE	-0.0325 (1.696)	-0.006		
MS	1.830** (0.725)	0.250	2.088** (0.732)	0.274
FCCG	-0.289 (0.652)	-0.028	-0.118 (0.586)	-0.011
SOIL			0.083* (0.063)	0.0316
SIZEADJ			0.850 (0.746)	0.161
Maddala R^2	0.23		0.24	
Log Likelihood	-50.893		-50.707	
Likelihood-Ratio Test	24.093		24.463	
Correct Predictions (%):				
Adopters	70.83		72.92	
Nonadopters	67.44		67.44	
Total	69.23		70.33	

Notes: Single and double asterisks (*) denote significance at the 10% and 1% levels (one-tailed test), respectively. Marginal effects for *EDUC*, *OWN*, *MS*, and *FCCG* are calculated by holding all variables at their sample means while evaluating the predicted values of adoption at the respective sample means of each binary variable and at a value of one.

Operators of farm units with relatively finer-textured soils are more likely to adopt level field or basin technology. The positive and negative coefficients on *AWC* and *INTAKE*, respectively, in Model 1 reflect this assertion, although they are not statistically significant (table 2). Variability in yields with the new technology (σ_ε^2) could be smaller for soils with higher available water-holding capacity and lower intake rates.

Relative profitability [the numerator in equation (5)] could be higher on these soils. The positive and significant sign on the variable *SOIL* in Model 2 supports the recommendations of the agricultural engineering literature regarding the soil criteria for designing level field and basin irrigation systems. In addition, the relatively large marginal effect (0.274) on *AWC* in Model 1 indicates the large impact a marginal increase in water-holding capacity has on the adoption decision.

These results are contrary to the general conclusions of several previous studies (Caswell and Zilberman; Lichtenberg; Dinar and Yaron; and Green et al.) which predict higher adoption rates of land-augmenting technologies (e.g., drip and sprinkler irrigation) on poorer quality soils (i.e., relatively lower *AWC*, higher *INTAKE*, and lower *SOIL*). This conflict is explained by the nature of the investments in level fields and basins. Leveling fields to zero slope, like drip irrigation, represents a modern irrigation technology because it has the potential to increase water application uniformity, enable the producer to use water more efficiently, give the operator more management flexibility by reducing set times, and save on irrigation labor. Level basin technology requires fields with low intake rates so irrigation water has the opportunity to move efficiently across the field. Only with low infiltration rates can the water application be managed to increase application uniformity. Pressurized drip or sprinkler systems are not as dependent on gravity or water velocity to ensure uniformity, and therefore are more likely to be used on lands where the marginal gains from improved water management are the greatest (i.e., land with lower *AWC*). But since both level basins and pressurized systems are water-conserving and land-augmenting technologies, we conclude that the adoption decision is dependent not only on soil characteristics, but on the technical nature of the irrigation system in question. Negri and Brooks, and more recently Green and Sunding, found that physical land characteristics play an important role in technology choices.

The growers in the Maricopa-Stanfield (MS) farming area had a significantly higher probability of adopting level fields and basins when compared to their counterparts in the Florence-Coolidge-Casa Grande (FCCG) and Central Arizona (CA) regions (table 2). The relatively large marginal effect (0.250) indicates that growers in MS are much more likely to adopt level fields and basins, ceteris paribus. Several factors possibly explain this behavior. During the study period, the MS area experienced relatively larger declines in ground water levels and higher absolute depths to water due to increased pumping. These conditions produced relatively higher water costs. In the early 1980s, farmers were convinced that long-run water costs would be less if they contracted for Central Arizona Project (CAP) water, as a partial substitute for well water, and adopted water-conserving irrigation technologies. Producers considered these decisions in their best interests for long-term survival. A contract was signed in 1983, and MS farmers began receiving Colorado River water in 1987. With an assessment charge of $99 per acre and a water cost of $54 per acre-foot, the CAP water cost was $20–$30 per acre-foot more than previous pump water costs.

Growers in the San Carlos Irrigation District, a major portion of the FCCG farming area, did not vote in the early 1980s to receive CAP water. Their water costs were approximately $21 an acre-foot during this period. Central Arizona (CA) growers contracted for CAP water in 1983, but their enthusiasm for accepting higher-cost surface water was dampened by relatively lower pumping costs due to shallower aquifers. Some CA farms began receiving CAP water in 1987. At the end of the study period, the net

Table 3. Estimated Diffusion Paths for Level Field and Basin Technology

Model	b_0 Constant	b_1 Diffusion Rate	$\overline{R}^2$	Durbin-Watson Statistic
Aggregate (1968–89)	-450.94	0.227	0.99	1.735
	(19.34)	(0.01)		
Innovators and Early Adopters (1968–89)	-447.03	0.225	0.99	1.556
	(24.53)	(0.01)		
Early Majority (1982–89)	-552.80	0.278	0.96	1.364
	(58.60)	(0.03)		

Notes: A 70% ceiling was developed from ADWR goals for the Pinal AMA. Numbers in parentheses are standard errors.

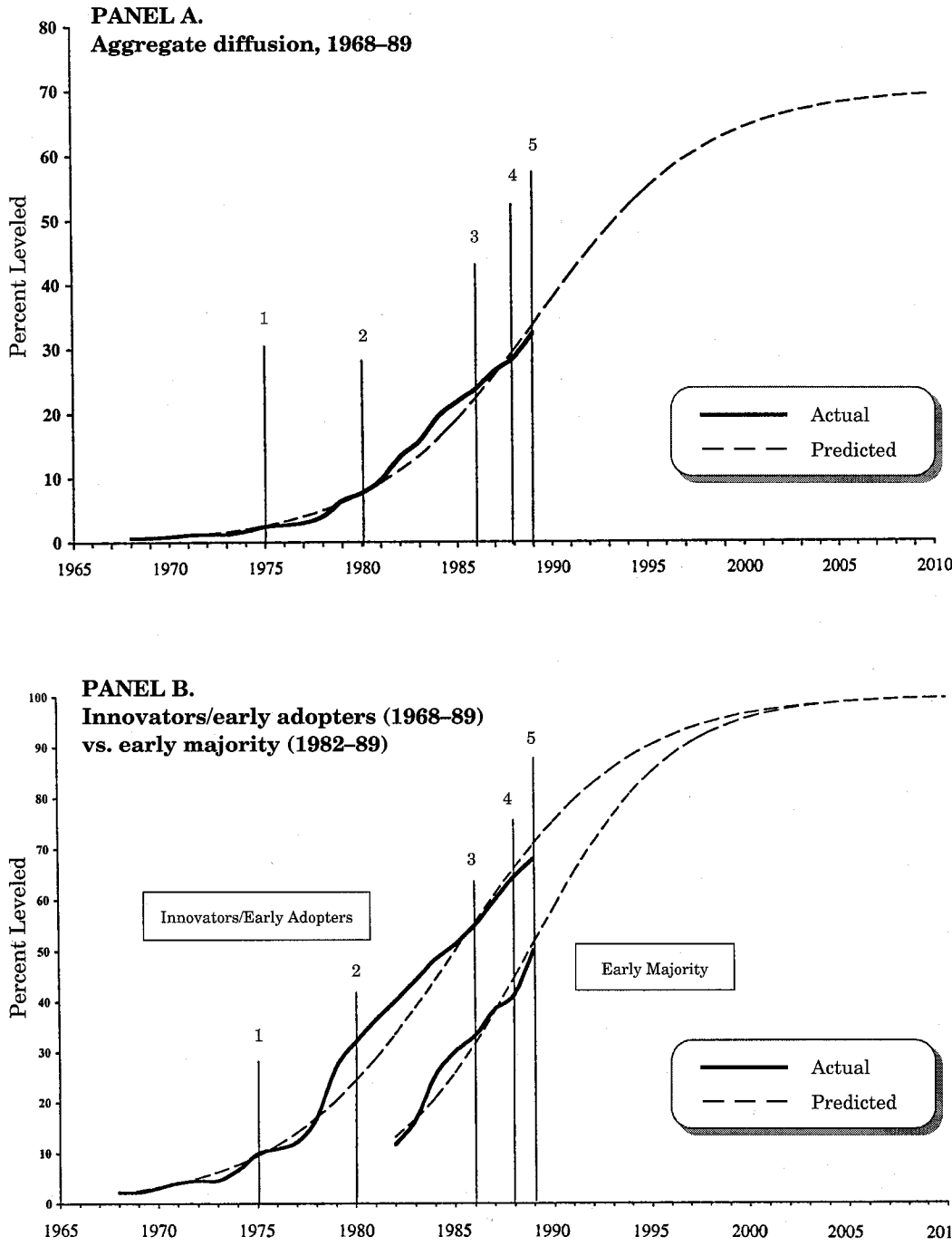
CAP water assessment for CA producers was \$10–\$50 per acre and the per acre-foot cost was \$50.

By making the democratic decision to sign long-term contracts for CAP water, the growers in the MS and CA subregions locked themselves into a system of administratively determined prices over which they had little control. Grower control was lost in terms of the size of the irrigation head since the surface and pump water were now controlled by a central authority (e.g., the Maricopa-Stanfield Irrigation and Drainage District) which delivered a uniform, high-volume head of water to the farm turnout. In addition, the farmer lost some control over the timing of the irrigation water. Since several irrigation districts did not employ a night shift, turn-on and turn-off times for the farms might not be optimal, thereby increasing water bills. The institutional decision to contract for CAP water through a district authority may have induced producers to adopt a water-conserving irrigation technology since they were in effect substituting a lower cost input (well water), at least in the short run, with one at a higher price (surface water) (Bush and Martin). The impact of these contracting decisions on aggregate adoption is illustrated in the diffusion path of level basin technology in the Pinal AMA. However, this illogical economic decision, ceteris paribus, would haunt growers in the early 1990s (Wilson 1992, 1997).

Diffusion

The policy goal of the Arizona Department of Water Resources is 182,000 acres of level fields and basins by the year 2000, the end of the second management plan. This acreage figure represents 70% of the cropland in the Pinal AMA. Thirty-two percent of the crop acres had been leveled, representing slightly less than 50% of the goal. The statistical results are presented in table 3, and the actual diffusion data are overlayed with the estimated/predicted diffusion curve in figure 1 (panel A). A ceiling of 70% produces a speed of adoption of 0.227. The logistic function characterizes the data well by explaining 99% of the variability in cumulative adoption.

During the 1968–75 period, there was minimal land leveling to zero slope (figure 1, panel A). Granted, laser technology had not yet been introduced in the region during



KEY:
1 = Laser-leveling technology introduced in Wellton-Mohawk (1975).
2 = Passage of the Groundwater Management Act (1980).
3 = First Central Arizona Project (CAP) water arrives in the Pinal AMA for irrigation (1986).
4 = Initiation in the Pinal AMA of publicly funded grower education program for irrigation management (1988).
5 = Initiation of a federally and state supported cost-share program for farmers investing in level fields and basins in the Central Arizona (CA) region (1989).

Figure 1. Actual and predicted diffusion for level fields and basins

this period. However, the energy crisis beginning in 1973 dramatically increased energy rates. Yet these events had little impact on the decision to conserve water in the Pinal AMA through new irrigation technologies. Why? Federally subsidized energy rates and surface water costs dampened any incentive to improve irrigation uniformities in this area by adoption of nonmanagement strategies. In addition, the uncertainty surrounding the accuracy of traditional land-leveling techniques raised serious doubts about the water savings that the grower could expect to achieve with level fields or basins.

A two-year lag is evident in figure 1 between the introduction of laser leveling in the Wellton-Mohawk region and a noticeable increase in the dead-level acreage in the Pinal AMA. Significant levels of adoption began in 1978, increased in 1979, and tapered off by 1980. Leveling activities again picked up in 1981–82, shortly after the passage of the Groundwater Management Act, and surpassed the diffusion rate of the estimated diffusion curve until 1987. The leveling activity again slowed down in 1985 and 1986, but showed significant increases in 1987 and 1989. The actual data illustrate the cyclical nature of the diffusion path for level fields and basins. The discrete decision making of growers in response to (*a*) endogenous pressures to become more efficient (e.g., to lower per unit costs), or (*b*) exogenous shocks (e.g., responses to changes in government policy), generates intra-period S-curves in the post-laser and post-GMA (1981–86) periods.

The variability in diffusion patterns between classes of adopters further reflects this response to government policy and projected costs. In panel B of figure 1, we separated the actual/estimated diffusion curves for the innovators and early adopters (i.e., adopting prior to 1982) and the early majority (i.e., adopting in 1982 or later). We chose 1982 to differentiate these two groups because (*a*) it closely resembles the divisions in the traditional characterization of the probability distribution of the diffusion process (see Thirtle and Ruttan, p. 81), and (*b*) this year reflects the first year that most growers realistically could begin to level their fields after the passage of the GMA in late 1980. The leveling decisions of innovators and early adopters follow a traditional S-shaped diffusion pattern. This group of farmers responded in the 1970s to internal demands to improve water use efficiencies by dead-leveling some of their fields with traditional leveling methods. With the introduction of laser-leveling technology into the state in 1975, and a lag period of two years, the innovators and early adopters began a consistent leveling program that continued through 1989. By 1989, 68% of their irrigable land was leveled to zero slope. Our projection indicates, ceteris paribus, that over 95% of these producers' acreage will be level fields and basins by the year 2000.

The farmers labeled "early majority" reacted strongly to their perceptions of policy changes and long-run price movements. In 1982 alone, they leveled slightly over 10% of their acreage. In eight years, these later adopters had 50% of their acreage in level fields and basins. A comparison of the data in figure 1, panel B indicates that the learning-by-doing process was less pronounced in the case of the early majority. They learned their lessons from the innovators and early adopters and imitated their behavior. At the predicted speed of adoption, these relatively later adopters will have 96% of their acreage dead-leveled by the end of this decade.

A Postscript

Our statistical evidence indicates that the Arizona Department of Water Resources goal of 182,000 dead-leveled acres was an optimistic, but not unrealistic, target for the year 2000. According to our estimates, 65% of the acreage (169,000 acres) would be in level fields and basins by 2000, and a 70% adoption rate obtained by 2005–2010.

Feder and Slade argued that public agencies might need to "shock" growers with stricter conservation regulations, or induce farmers to adopt with research-based education programs and/or subsidies. All of these institutional changes were applied in the Pinal AMA in order to maintain this speed of diffusion. First, the second management plan for the Pinal AMA "shocked" growers with 75–85% irrigation efficiency rates. The increased acreage leveled between 1988 and 1989 represents the impact of these future efficiency rules.

Second, in 1987, the ADWR, in collaboration with local resource conservation districts and the NRCS, initiated the Irrigation Management Service (IMS) in the Pinal AMA. The stated purpose of the educational service was to help growers "achieve maximum irrigation efficiency" with their irrigation system, thereby reducing θ in our conceptual model. Evidence from the IMS program in 1990 indicated that operators were not achieving the projected water savings, $(w_g - w_f)$ in equation (5), attributable to the adoption of level fields and basins. Nor had yields increased due to improved uniformities, $[f(w_f) - g(w_g)]$ in equation (5). It may also be that potential yield increases were overstated. The leveling activity may be only part of the technology; on-farm water management (e.g., irrigation timing, application measurement) must become more intensive if potential gains are to be realized by the grower. Apparently, many growers in the Pinal AMA failed to make the necessary behavioral changes associated with level fields and basins. The detailed evaluation of water management practices in the Maricopa-Stanfield area confirmed the suboptimal behavioral changes by adopters of level fields (Dedrick et al.).

In late 1989, the Soil Conservation Service initiated an on-farm conservation improvement program in the Central Arizona (CA) Irrigation District, a subsidy program representing the third institutional tool mentioned by Feder and Slade. This 50/50 cost-share arrangement, which reduces P_L in our conceptual model, was meant to induce the adoption of level field technology by the "late majority" growers. Similar cost-share programs were implemented in the MS and FCCG regions in 1992. Yet by 1995, only 80,000 acres had been leveled to zero slope in the Pinal AMA. Uncertainty associated with cotton prices, water costs, and crop financing dampened growers' initial enthusiasm for continued investment in an irreversible technology.

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