QUANTIFYING LONG RUN AGRICULTURAL RISKS AND EVALUATING FARMER RESPONSES TO RISK

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Strategic Investments in Agriculture: How Do We Measure Risk?

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ABSTRACT

Decisions concerning strategic investments create risks associated with time and switching costs. In the case of cotton growers in Arizona, the decision to adopt laser leveled fields was positively related to farm size, and negatively related to age and soil intake rates. The diffusion of this strategic investment was more sensitive to changes in government policy than to variability in output and input prices.

Key words: adoption and diffusion, technological change, irrigation, laser leveling

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Technological change has long been identified as a driving force behind the changing structure and performance of the U.S. agricultural sector during the last fifty years. From the adoption of tractor power and hybrid seeds, to the reliance on agricultural chemicals to insure high yields, agricultural producers have been induced to adopt new production practices by the economic reality of the marketplace (Cochrane, 1979). Although consumers today are signaling a concern about the levels of agricultural chemicals used in food production, agricultural producers will continue to seek to gain cost advantages or cost leadership positions in their specific commodities by continuing to adopt new technologies.

Most agricultural technologies can be divided into two categories: operating and long-term. New operating innovations impact most directly on annual variable costs of production. Their use requires few to only moderate management changes and the decision to use the new technology is easily reversible. Several examples of new operating technologies would include improved seed varieties and pesticides, livestock implants and vaccinations, and the adoption of some farm equipment (e.g. microcomputers). In the case of long-term investments, the grower faces a decision which is costly to reverse and requires multi-year planning. These investments impact on both the variable and fixed costs of production, often require equity or debt financing, they may increase the scale of the production unit, and management may need to become more intense and professional. Examples of long-term investments include the purchase of new field equipment and machinery, the expansion of the farm and the adoption of new irrigation technology or equipment.

Within the class of long-term investments there is a group of managerial decisions which we will call strategic investments (Porter, 1980, 1985). Strategic investments are asset-acquisition decisions which position the firm in its competitive environment so it will prosper and survive over a given planning horizon. The key characteristic of strategic investments is the cost of switching to the new asset. These switching costs, either explicit or implicit, are attributed to costs of financing and

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financial risk, the irreversibility of the decision to acquire the asset, and the new demands asset acquisition places on management. Examples of strategic investments include farm expansion, adoption of a new irrigation technology and the entrance by the producer into a new crop or livestock market.

The objectives of this paper are (1) to briefly review the adoption and diffusion literature, giving specific attention to lessons learned about strategic investments, (2) to discuss the experience of cotton producers in Central Arizona in regard to laser leveling and (3) to introduce the concept of policy induced strategic investments in agriculture. This research process leads to the assertion that strategic investments are made when the decision maker is convinced that a permanent change has occurred in the business environment, often as a result of new government policies, which threatens the business' long-term economic viability.

Lessons Learned from the Literature

The adoption and diffusion of new agricultural technologies has been reviewed thoroughly by several analysts (Rogers, 1962; Feder, Just and Zilberman, 1984). Starting with the hybrid seed corn work of Ryan and Gross (1943), and later Gross (1947), researchers discovered that adoption of agricultural innovations is 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 non-adopters. Griliches (1950,1960) complemented these earlier studies by introducing expected profitability as a critical variable in the adoption process. Griliches found that the adoption of hybrid seed corn followed a S-shaped logistic curve, with the adoption of the innovation being more rapid in areas which profited the most from the new technology (Iowa versus Georgia).

In recent years Jensen (1982) and Balcer and Lippman (1984) have attempted to put the process of adoption and diffusion on stronger theoretical grounds. By incorporating perceptions and learning in a Bayesian framework, and recognizing expected profits and the variability of profits associated with conventional and new technologies, the authors proved rigorously that a S-shaped diffusion curve is an expected result of the adoption process. These purely theoretical analyses have been complemented in the agricultural economics literature by the work of Gershon Feder and several co-authors.

Feder (1980) introduced a formal production model to address the role of risk aversion and credit constraints in the adoption of high yielding seed varieties. In comparing a no risk conventional crop to a fertilizer dependent new crop, Feder found that the optimal level of fertilizer use was independent of risk aversion or farm size. Only the allocation of land to the modern crop was negatively influenced by changes in risk preferences. Feder and O'Mara (1981, 1982) used a similar model to analyze the adoption and diffusion of scale-neutral green revolution innovations: hybrid seeds, chemical inputs and new cultural practices. Fixed costs were introduced as the cost involved in gathering information about the new technologies, and the necessary time to secure financing and the other production inputs associated with the innovation. As a result, farms below a critical size did not adopt the green revolution technologies.

Uncertainty and the costs of acquiring information were too high. However, over time and with policies that reduce fixed costs(e.g. extension, timely credit and subsidies), small farmers do increase their rate of adoption and an S-shaped diffusion curve resulted. Feder (1982) extended this work to include scale neutral (e.g. seed) and lumpy innovations (e.g. tractors) to show the differential impact of farm size, credit and subsidies would have on the adoption of the new technologies. Finally, Feder and Slade (1984,1985) used a Bayesian framework to model the acquisition of information about an innovation. Since the process of seeking information is costly in terms of time and money, farm size, risk attitudes and government policies (e.g. taxes, subsidies) become important variables in determining the rate of adoption and diffusion. This later work is supportive of the earlier findings of Hiebert (1974).

The above articles are extremely limited in empirical content. Results are derived from optimizing Bayesian or expected utility models and interpreting first-order or comparable conditions. However, several examples of empirical research are Jarvis (1981) for improved pastures in Argentina, Lee and Stewart (1983) for the adoption of minimum or conservation tillage practices, Caswell and Zilberman (1986) for new irrigation technologies, and Pulter and Zilberman (1988) concerning the adoption of microcomputers by California farmers. The Caswell and Zilberman article is of particular importance to this paper. Using a farm production model incorporating soil quality and well depth, the authors derived comparative static conditions, and later verified them using econometric analysis, for the adoption of land-augmenting irrigation technologies. Low land quality and expensive water encouraged the adoption of drip and sprinkler systems. Farms with heavy soils and cheap water continued to use traditional flood and furrow irrigation. The authors showed that the new technologies had to be profitable (i.e. increase yields) in order to be adopted by the grower.

As a summary of the preceding literature, a simple model can be used to isolate the critical variables in the adoption decision concerning a new technology (Robison and Barry, 1987, pp. 284-293). Suppose the cotton grower has the option of dividing his acreage (L) between a risky new technology, dead level fields(S), and risk-free furrow irrigation (L-S). The per acre net returns to the new technology are $R_1 + \epsilon$, where ϵ has a mean of zero and a variance of σ^2_ϵ, and R_2 are the net returns for furrow irrigation. The grower's risk attitudes are measured by the Arrow-Pratt coefficient (l). The certainty equivalent profit model for this decision maker can be written as:

$$\max \ \pi_{CE} = R_1 + R_2(L - S) - \frac{\lambda}{2} S^2 \sigma_\epsilon^2 \qquad (1)$$

where the first derivative produces an optimal level of dead level acreage of:

$$S = \frac{R_1 - R_2}{\lambda \sigma_\epsilon^2} \quad \text{for} \quad 0 \leq S \leq L \qquad (2)$$

This implies that expected profits associated with the new technology must be greater than the certain profits of the conventional or traditional technology. Secondly, the level of adoption is positively influenced by lower levels of risk aversion. Finally, information acquisition, learning and experience reduce σ^2_ϵ and increase the rate of adoption.

The reviewed models generate little insight into the decision to make a strategic investment. Most of the literature discusses the adoption and diffusion of operating inputs. Fixed costs, irreversibility and other time considerations play insignificant roles in these analyzes. In addition, the empirical testing of the theoretical models is embryonic at best. Most of the literature has been directed at technological change issues in low income countries whereas the adoption and diffusion of innovations in the U.S. has received much less attention.

Laser Leveling in Arizona: A Case Study

Under pressure from the Bureau of Reclamation, the Arizona State Legislature passed the Groundwater Management Act (GMA) in 1980 in order to regulate the use of ground water in six areas of the state and insure continued federal funding for the Central Arizona Project (CAP). Active Management Areas (AMA) were established in three important agricultural/urban areas where a long history of ground water overdraft threatened the long-term viability of farming. Water use now is regulated through a series of management plans which increasingly enforce water conservation practices in both the rural and urban areas. Safe yield or zero overdraft is the goal in 2025 for three of the AMAs (Phoenix, Prescott and Tucson) while the Pinal AMA, the more agriculturally dependent region, will maintain its agricultural base for as long as possible under tightening water use requirements. Irrigation Non-expansion Areas (INA) also were established in two small, rural regions to regulate the future growth of ground water pumping for agricultural and urban use.

Agricultural producers in the AMAs are assigned a water duty each year which is a function of their historical (1975-1979) cropping patterns, plant requirements and an institutionally-determined irrigation efficiency established by the Arizona Department of Water Resources (ADWR). This duty establishes the amount of water the grower can pump from the farm's wells during the year. Water use is measured by flow meters on all wells and randomly monitored by ADWR staff. By increasing the irrigation efficiency in each management plan, the ADWR hopes to encourage farmers to adopt water-conserving irrigation technologies which will help the AMA reach its legislated goals. For example, in the Second Management Plan (1990-1999) for the Pinal AMA the irrigation efficiencies for row crop farms are being raised to 80-85 percent, a rather dramatic increase over the 60-70 percent level established in the first plan (1984-1989). Grower expectations of these higher efficiencies have led to increased interest in laser leveling (Daubert and Ayer, 1982), surface and subsurface drip irrigation (Wilson, Ayer and Snider, 1984), linear move technology (Wilson, Coupal and Hart, 1987) and surge flow irrigation (Coupal and Wilson, 1990).

Laser leveling is a land-augmenting technology first used by the Soil Conservation Service (SCS) in the Midwest during the early 1970's to lay drainage tile. This technology was brought to Arizona in 1975. Its introduction in the Wellton-

Mohawk region of Yuma County, outside of any future AMA or INA, was encouraged by the SCS as it attempted to increase irrigation efficiencies (Erie and Dedrick, 1978). This concern for water-conserving practices in a region experiencing low, federally-subsidized water prices arose from an international treaty with Mexico in 1974 which insured the quality of water crossing the U.S.-Mexico border in the Colorado River. By using less irrigation water on a per acre basis, the salinity level of the instream flow and return flow to the river from the Wellton-Mohawk Irrigation District could be maintained at agriculturally acceptable levels for Mexican producers. Through a federally-supported cost share program, with the government paying 75 percent of the leveling costs, 50,000 acres of crop land were laser leveled over a four year period.

Farm land traditionally was leveled by surveying and staking fields to show the equipment operator where cuts and fills were to be made. Achieving the desired grade or non-grade was dependent on the skill of the equipment operator and high and low spots often remained in many fields. This difficulty was overcome by laser beam emitting tripods set up in the center of the field which, through a receiver attached to the earthmoving equipment, lowers or raises the scraper blade on a continuous basis. Laser leveling facilitates the establishment of dead-level fields or fields with a slope of less than 0.2 feet over a one quarter mile irrigation run. Dead-level fields, with improved management, reduce deep percolation losses, allow the grower to handle large heads (e.g. 3000-6000 gpm) of irrigation water delivered by the Central Arizona Project (CAP), and increase the uniformity of irrigation water across the field thereby increasing the probability of higher crop yields. The cost of leveling a field to zero slope is a function of the cubic yards of soil moved and the need to replace irrigation ditches and redesign field layouts. Total investment costs during the 1980's have ranged from $100-600 per acre.

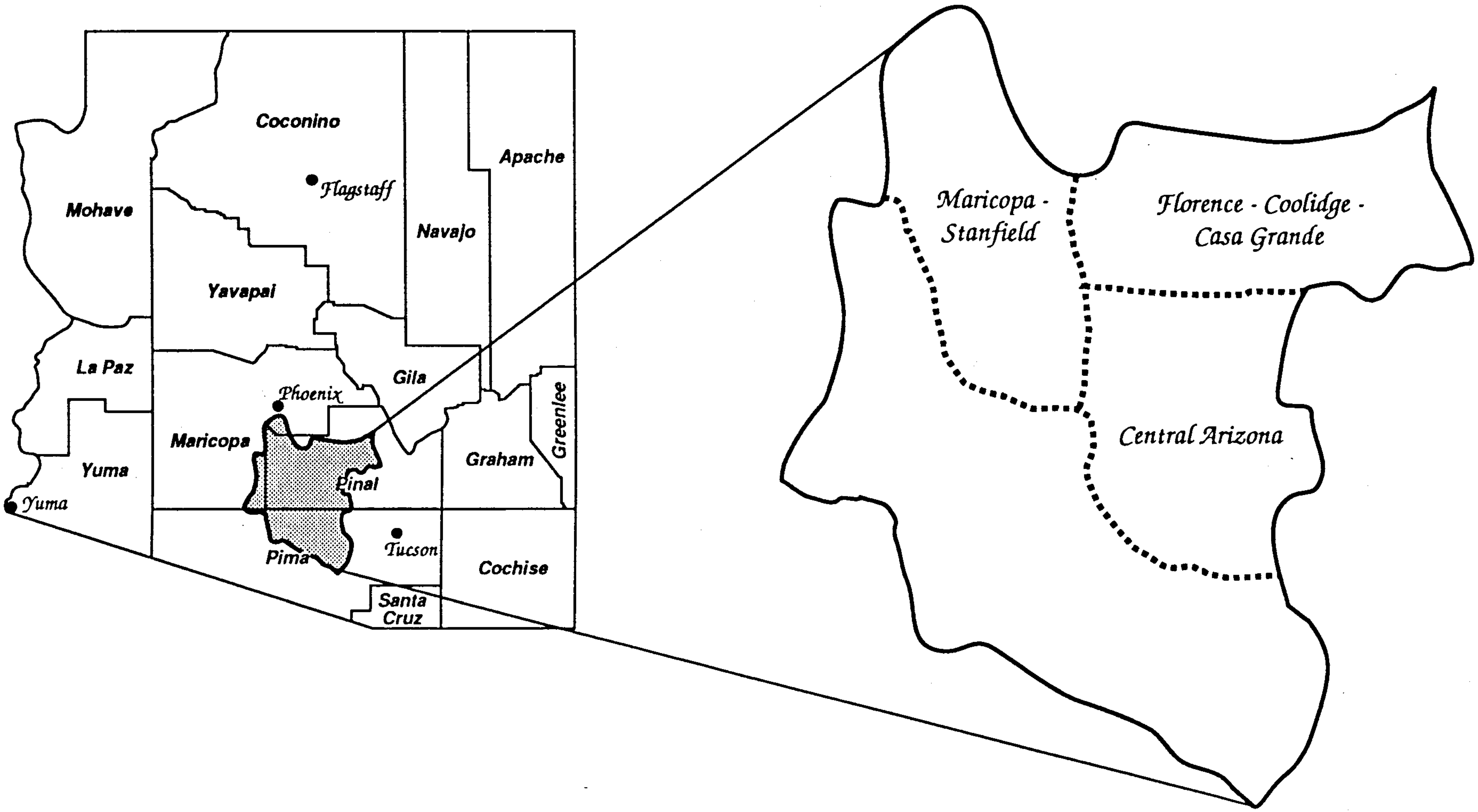
Data and Analytical Models

A stratified random sample of farming units in the Pinal AMA was taken from ADWR records of irrigation grandfathered rights. Farms were stratified two ways: by size in crop acres (100-199, 200-499, 500-999, 1000+) and area of similar management practices (Maricopa-Stanfield, Florence-Coolidge-Casa Grande, Central Arizona) (Figure 1). Farms with fewer than 100 acres were not accounted for in this study because most of this land is either leased to larger growers, or in most cases these small land units are operated as hobby farms or ranches on a part-time basis.

Of the 558 farm units in these size categories, 100 were selected randomly for inclusion in this study. A phone survey instrument was developed in cooperation with SCS and ADWR technical personnel. Soils data was obtained from SCS soil maps and cooperator files. Surveys were completed on 86 percent of the target farms. This success rate produces a confidence interval of eight percent for the estimate of laser-leveled acreage in the Pinal AMA.

A logit model was used to characterize the decision to adopt or not adopt laser leveling technology. The adoption model is specified as:

Figure 1. Pinal Active Management Area and Farming Regions of Similar Management Practices.



$$P_i = \frac{1}{1 + e^{-z_i}} = \frac{1}{1 + e^{-(\propto + \beta_1 X_1 + \beta_2 X_2 + \ldots + \beta_7 X_7)}} \quad (3)$$

where P_i is the probability that a grower will chose to adopt and X_i represents the socio-economic and physical variables which are hypothesized to influence the adoption decision. Actual age of the decision maker at the time of adoption 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 was measured by a qualitative variable with the value of one for an individual who had some additional education beyond high school graduation and zero for growers with a high school education or less. The expectation was that a positive relationship would be found between education and a favorable adoption decision due to the relatively more educated respondent's increased ability to gather, assimilate and analyze information. Ownership also was measured as a dummy variable by taking on the value of one if the grower had an ownership interest in the farm unit and zero for land that was leased from the state, individuals, or estates and trusts. Historically, private ownership has encouraged the early adoption of profitable agricultural technologies.

Four physical or locational variables were included in the logit model: total acres farmed, surveyed farm size, soil intake rate, and irrigation region. The total acres farmed variable serves as a proxy variable for net worth of the respondent. Many respondents in the sample farmed multiple farm units. It was hypothesized that these growers would have the financial resources to make an early decision to invest in dead-level fields. Surveyed farm size is the crop acres of the farm unit identified in the irrigation grandfathered right on file with the ADWR. Again the relationship between this size variable and the adoption decision was expected to be positive. Weighted average soil intake rates were obtained from cooperator records and soil maps for each farm unit. Jensen (1983) has emphasized that soil intake rate or infiltration, measured in inches per hour, is a critical variable in determining the appropriateness and efficiency of an irrigation system or technology. Finally, the location of the farm in the AMA was denoted by qualitative variables indicating one of the three areas of similar farming practices. These areas are differentiated to an extent by ground water pumping lifts, surface water supplies, soils and institutional arrangements. These differences will be discussed further in the results section.

A logistic curve was used to trace the diffusion path of innovations in the Pinal AMA. This S-shaped curve models the low number of innovators and early adopters who first use the technology. As information is generated by these growers, the rate of diffusion increases as more farmers adopt. Eventually, diffusion begins to slow down and asymtotically approaches a ceiling of the total number of producers who will adopt the innovation. The logistic curve used in this research is defined as:

$$Z_t = \frac{K}{1 + e^{-(c + \varnothing_o t + \varnothing_1 X t)}} \quad (4)$$

where Z_t is the cumulative number of laser-leveled acres in year t, K is the ceiling of laser-leveled acres and X is an explanatory variable, besides time, which explains the diffusion path. The selected diffusion period was 1968-1989. Although laser leveling technology was not available in Arizona until 1975, the 1968-1975 period was included because during these years several growers reported leveling their fields to zero slope with conventional techniques as energy prices increased, especially in the early 1970's. Explanatory variables (X) used to estimate equation 4 included real and nominal cotton prices, electrical rates, interest rate, and four year moving coefficients of variation for cotton prices and electrical rates.

Results

Age, surveyed farm size, soil intake rate and the Maricopa-Stanfield farming area are the significant explanatory variables in the adoption decision (Table 1). Younger growers have a longer planning horizon and are more likely to enjoy the rewards of land-augmenting technologies as they accrue to the farm operator over a long time period. 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 before retirement. The education variable has the hypothesized sign but was statistically insignificant. This result may be explained by the high education level of most of the respondents, thereby reducing the level of variability in this explanatory variable.

Table 1: Logit Regression Results for the Adoption Decision of Dead-Level Fields

Variable	Estimated Coefficient	Asymptotic Standard Error	t-Ratio
Constant	7.8	2.6	2.97
Age	-0.131	0.04	-3.70
Education	0.389	0.80	0.49
Ownership	-0.730	0.63	-1.16
Total Acres Farmed	-0.0008	0.0005	-1.70
Surveyed Farm Size	0.0023	0.001	2.48
Soil Intake	-3.47	1.60	-2.16
Maricopa-Stanfield	1.87	0.96	1.94
Florence-Coolidge-Casa Grande	-0.69	0.87	0.80
Log Likelihood	-34.927		
Correct Prediction (%)	Total 82.56	Adopters 84.78	Nonadopters 80.00

Ownership did not significantly influence the decision to adopt the new technology. In fact, the negative sign is opposite the hypothesized relationship. One explanation is the long-term nature of leasing arrangements in the Pinal AMA. Private and state leases often are written for up to ten years with provisions for renewals if the grower meets the conditions specified in the lease agreement. In many cases strategic investments made by the lessee are protected under the lease. Upon cancelation of the lease prior to the expiration date, the lessor would have to reimburse the lessee for all capital improvements made to the property. Therefore, under these conditions the grower may not be deterred from making land-augmenting investments on leased property.

Laser leveling is more likely to be adopted on larger farm units. However, total acres farmed by the respondent had a negative, although insignificant, sign which appears to contradict the preceding result. A possible explanation is the fractured nature of farming in the Pinal AMA. Some growers farm one or two relatively large farms (400-500 acres each) while other growers farm four to five smaller farm units but more total acreage. These farm units may be located throughout the AMA. The results may be indicating that there are some inducements to innovate when fewer management or farming units are involved in the total farming operation. This tentative explanation needs further testing in followup research in similar farming regions.

Operators of farms with low intake soils were more likely to adopt laser leveling technology. This result supports the recommendations of the agricultural engineering literature but is contrary to the general conclusion of Caswell and Zilberman's work which predicted higher adoption rates of drip and sprinkler technologies on poorer quality soils. This apparent conflict can be explained by the nature of these strategic investments. Dead-level fields require low intake rates so the irrigation water has the opportunity to move across the field. Only with low infiltration rates can the water application be managed to increase application uniformity. Pressurized systems are not as dependent on gravity or water velocity to insure uniformity and therefore are more likely to be used on lands where the marginal gains from improved water management are the greatest.

The growers in the Maricopa-Stanfield farming area had a higher probability of adopting laser leveling when compared to their counterparts in the Florence-Coolidge-Casa Grande or Central Arizona regions. The principal explanation for this phenomena is the relatively larger decline in ground water levels in the Maricopa-Stanfield area and the higher average depths to water in this region (ADWR, 1988). Farmers in this area have apparently recognized that the adoption of water conserving irrigation technology is a necessary condition for their long-term survival. Also, growers in the Florence-Coolidge-Casa Grande area receive surface water through a federally supported distribution system which dampens the incentive to conserve water.

Actual and estimated diffusion paths for laser-leveling technology are presented in Figure 2. Using the Cochrane-Orcutt procedure to reduce autocorrelation, the estimation procedure found that only time was a significant explanatory variable. Estimated parameters (t-ratios in parentheses) for an adoption ceiling (K) of 60 percent were $c = -487.4$ (17.4) and $\emptyset_0 = .245$ (17.32) with an $R^2 = .987$ and Durbin-Watson Statistic of 1.813. Similar results were obtained for the 50 and 70 percent ceilings. These estimated equations were projected into the future until 95 percent of the target ceiling was obtained.

During the 1968-1975 period there was very little activity leveling land to zero slope. Granted, the laser technology was not yet introduced to the region during this period. However, the energy crisis beginning in 1973 dramatically increased energy cancelation of the lease prior to the expiration date, the lessor would have to reimburse the lessee for all capital improvements made to the property. Therefore, under these conditions the grower may not be deterred from making land-augmenting investments on leased property.

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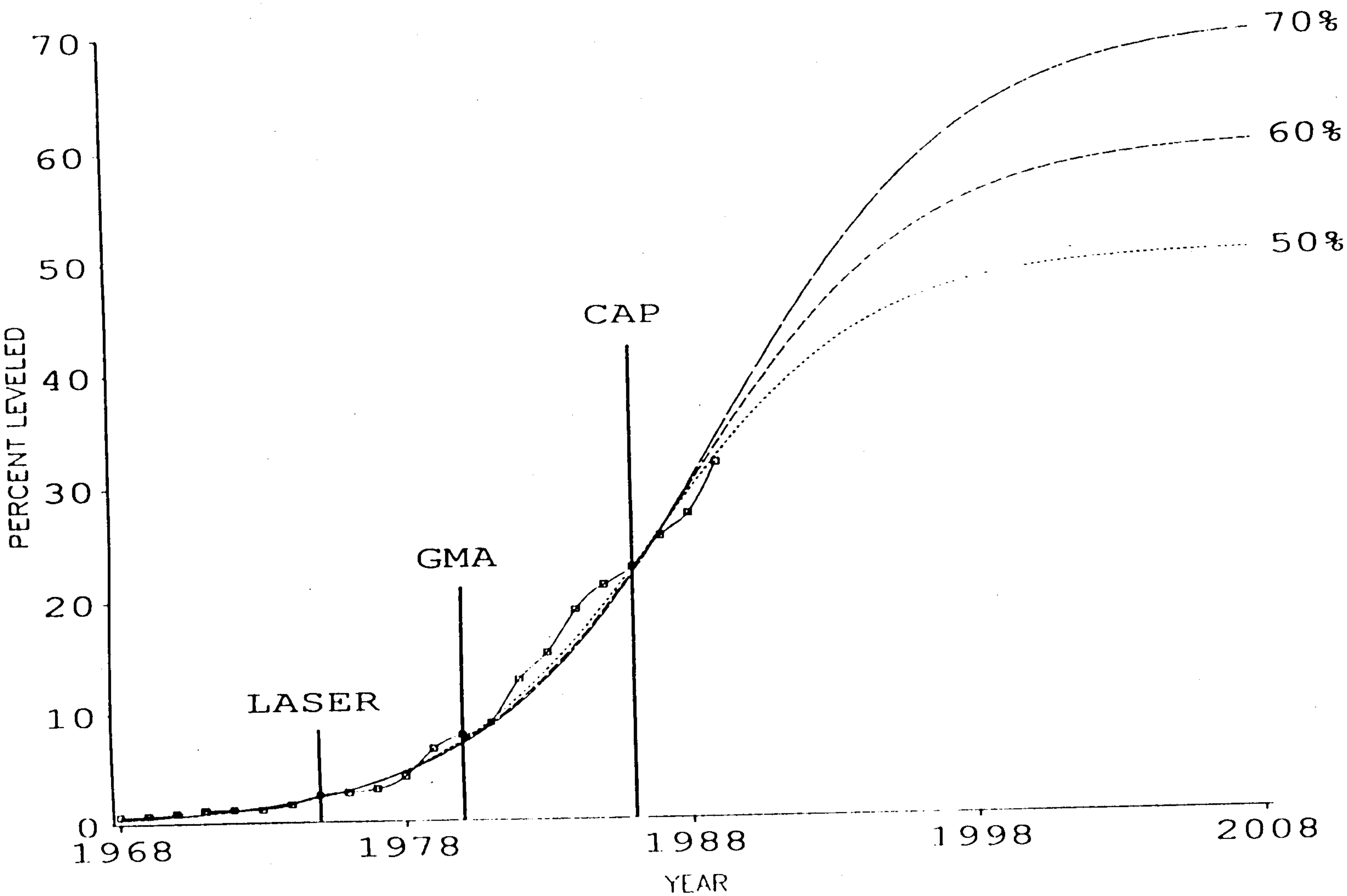
Figure 2: Actual and Predicted Diffusion Paths for Laser-Leveling



rates but had little impact on the decision to conserve water through increased irrigation efficiencies. Subsidized energy rates and surface water costs reduced the incentive to improve water distribution. In addition, the uncertainty surrounding the accuracy of traditional land leveling techniques raised serious questions about the true water savings that would have been realized by the grower.

With the introduction of laser-leveling in the Wellton-Mohawk area of Yuma County we find a lag of two years before a noticeable change in dead-level acreage is realized in the Pinal AMA. Early adoption began in 1978, increased in 1979 and tapered off in 1980. With the passage of the Groundwater Management Act of 1980, growers again increased their leveling activities after a lag of one year with significant increases in leveled acreage in 1982 and 1984. Again the leveling activity slowed down in 1985 and 1986 but experienced further increases in laser leveling in 1987 and 1989. Central Arizona Project (CAP) water was first delivered to a small number of growers in 1986 and since then more growers have begun to accept deliveries of CAP water.

By 1989 slightly over 30 percent of the crop acres in the Pinal AMA had been laser leveled to zero slope. Our projections show that the ADWR goal of 80 percent adoption is an unrealistic target by the year 1999. A 70 percent ceiling may be attained by 2009. Even in order to reach this adoption level the ADWR may have to "shock" the growers with strict conservation regulations in the second management plan or induce the farmers to adopt the technology with subsidies or research-based education programs (Feder and Slade, 1985). Some combination of higher, mandated irrigation efficiencies and improved public education concerning the benefits and costs of laser leveling will be necessary to meet institutional goals.

Concluding Remarks

Although the results concerning the adoption decision are in line with previously published work concerning innovations, the diffusion results from the Pinal AMA generate several stimulating observations. First, the actual diffusion curve indicates that market-based relative price changes have little impact on strategic investments in an environment of subsidized inputs. Higher energy prices in the 1970's did not induce cotton growers toward more water conserving irrigation technologies. Long-term contracts for hydroelectric power and subsidized surface water supplies cushioned the impact of rising electrical rates.

In this type of economic environment, changes in government policy appear to have a dramatic impact on the decision to innovate and adopt a strategic investment. The international treaty with Mexico in 1974, the Groundwater Management Act of 1980 and its individual management plans, and the Central Arizona Project represent major policy decisions which changed the political, economic and technological environment of Arizona agriculture. Although the passage of these laws produced the perception of long-run relative price changes, these new policies were politically generated, not induced by market forces. Therefore, laser leveling to zero slope represents a policy-induced strategic investment which is a rational response to evolving government policies in agriculture.

A third conclusion from this research is the apparent need for continued policy change if the desired water conservation goals are to be realized. The estimated logistic functions trace a smooth diffusion path over a 40-year planning period. These mega or envelope diffusion curves accurately reflect cumulative adoption rates for operating and long-term technological change. But embedded in the mega curve are a series of intra-period diffusion curves. These intra-period S-curves can be easily seen in the post-laser, GMA and CAP periods illustrated in Figure 2. This result is supportive of the second conclusion regarding the need for continued policy change in order to reach established policy objectives. Strategic innovations are made when changes in the policy environment induce adoption and are perceived to be permanent additions to the decision maker's economic environment.

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