Influence of Quality and Scarcity of Inputs on the Adoption of Modern Irrigation Technologies

Ariel Dinar and Dan Yaron

This article describes the influence of input quality and scarcity, environmental conditions, human capital, water price, and other variables on adoption rates for modern irrigation technologies in terms of both speed and extent of application. An empirical model is developed to apply these relationships to citrus groves in Israel. Results show that modern irrigation technologies tend to be adopted sooner and to a greater extent (*a*) on groves located on relatively low quality land, (*b*) in regions with higher evaporation rates, (*c*) on groves planted with more sensitive rootstock, and (*d*) on groves grown under conditions of restricted water allotments and higher water prices. Management, human capital, and scale of operation also affect the level and speed of adoption. It is suggested that water prices and quotas can be used to increase adoption.

Key words: technology adoption, input scarcity, input quality, irrigation.

Input quality is of major importance in both agricultural production and the adoption of new technologies (Rosenman; Caswell and Zilberman 1986). Soil and water are interacting inputs which affect the production of field and orchard crops. Water scarcity and poor soil may restrict farming activities at many sites, and salinity and other water quality factors can influence soil characteristics. Soil quality including salinity, depth, and water holding capacity, in turn, influences the access of the plant to water.

At many sites, the quality of water and land available for irrigated agriculture deteriorates over time (Messer). This is partially due to use of more brackish and recycled water over time which redounds to drainage and salinity problems. Recent improvements, such as pressurized and low-volume irrigation technologies, can combat water and land quality problems and can sometimes allow growers to maintain profitability (Letey et al.). Providing modern irrigation technologies to regions with low quality soil and water can sustain their economic vitality.

Modern irrigation technologies such as sprinklers, microsprinklers, and drip irrigation have become widely used; however, the literature on adoption of these irrigation technologies is relatively limited. Most of the literature has measured adoption rates using a discrete choice framework. This may not be appropriate for modern technologies that are field divisible, that is, where a given field can be equipped with more than one technology. Reliable databases on adoption of irrigation technologies at the field or farm level are scarce (e.g., Caswell and Zilberman 1985—county-level data and two technologies; Lichtenberg—county-level data and one technology; and Negri and Brooks—farm-level data and two technologies).

Ariel Dinar is a visiting researcher in the Department of Agricultural Economics, University of California, Davis. During the course of this study, he was with the Department of Agricultural Economics and Management, the Hebrew University of Jerusalem. Dan Yaron is a professor in the Department of Agricultural Economics and Management, the Hebrew University of Jerusalem.

This study was supported in part by a grant from the U.S. Agency for International Development, in juncture with the USDA, Office of International Cooperation and Development to the Hebrew University of Jerusalem as part of a trinational Egypt, Israel, U.S. project—Patterns of Agricultural Technology Exchange and Cooperation in a Similar Ecosystem: The Case of Egypt and Israel.

The authors thank the specialists of the Agricultural Extension Service in Israel and Gaza for help in data collection and several *Journal* reviewers for constructive comments.

Western Journal of Agricultural Economics, 15(2): 224–233

This article presents an empirical model of irrigation technology adoption which extends existing economic literature. Level of adoption is expressed as a continuous variable using alternative measurements. In addition to estimating the effects of soil, water, and rootstock quality, water price, and various regional conditions, it also estimates the effects of human capital, management, scale of operation, and other variables. Some of these effects were estimated separately in the past due to data restrictions. The analysis uses a rich cross-section database with information on the use of six irrigation technologies in Israel, a country where many of the modern technologies were first introduced. Conclusions are presented which extend and verify some previously unconfirmed hypotheses.

Literature Review and Conceptual Framework

The economic literature on adoption of agricultural technologies generally employs several key variables to explain levels of adoption. Among these variables are input and output prices, the decision unit dimensions (field and farm size), and human capital. In general it has been found that (*a*) an increase in input and output prices increases a grower's likelihood to adopt (Caswell and Zilberman 1985; Housmann; Jarvis); (*b*) larger units are more likely to adopt (Rahm and Huffman; Putler and Zilberman; Feder); and (*c*) human capital variables such as age, education, and experience also affect the likelihood to adopt (Huffman; Rahm and Huffman; Putler and Zilberman).

Several studies have addressed the role of input quality on the adoption of modern irrigation technologies. Caswell and Zilberman (1986) established a theoretical framework emphasizing the capacity of modern irrigation technologies to increase irrigation effectiveness as measured by the ratio of evapotranspiration to applied water. The tendency to adopt a new technology is greater for growers with low quality lands. Incorporating this factor into a profit-maximization framework, Caswell and Zilberman (1986) argued that adopting modern irrigation technologies likely would increase yield and save water. They also suggested that there is a greater tendency to adopt modern irrigation technologies in locations where land quality is poor and output and water prices are high. These hypotheses generally were confirmed by Lichtenberg for center pivot irrigation in Nebraska, by Caswell and Zilberman (1985) for drip irrigation and sprinklers in central and northern California, and by Negri and Brooks for sprinklers using census data from 30 states.

Conversely, Feinerman, Letey, and Vaux concluded that, given the functional form of the crop water production function, an increase in the relative price of water may induce technological and managerial improvements which increase productivity and increase water use. In a study of drip irrigation adoption in central Israel, Feinerman and Yaron confirmed empirically that the adoption of drip in cotton has increased crop yields and water applications per hectare (ha). Dinar, Letey, and Knapp have found that crops irrigated with saline water using modern technologies characterized by relatively high irrigation uniformities obtain higher levels of yield for the same application rates than with gravitational systems such as furrow, which are characterized by lower irrigation uniformities.

The impact on adoption of human capital variables, such as age, education, and experience, has been evaluated in several studies (e.g., Huffman; Rahm and Huffman). Generally it was found that higher levels of human capital are likely to induce adoption, although this finding is strongly influenced by the specific human capital variable measured. In the case of experience, a higher level may diminish the likelihood to adopt.

Empirical and theoretical evidence cited in Feder, Just, and Zilberman's survey suggests that while farmers with larger units are more likely to be early adopters, over time a greater percentage of land is converted to modern technologies on smaller farms. The type of farm organization is expected to affect adoption of modern technologies. Molcho and Katz showed that farmers in *kibbutz* (collective) settlements are more likely to adopt modern technologies than farmers in *moshav* (cooperative) settlements. The organization type of the *kibbutz* settlement, they argued, provides better support for its decision makers (e.g., information availability, financial security). Findings by Kislev and Shchori-Bachrach also suggested that adoption is more likely within *kibbutz* farms.

Most of the studies on adoption of irrigation technologies have dealt with annual crops.

Those studies related to perennial tree fruits (Caswell and Zilberman 1985) did not include the effect of the grove's age on adoption. Agronomic studies have shown that younger groves have relatively restricted root zones. Younger groves respond better to modern technologies which can be adjusted to meet the needs of individual trees. Older groves with deeper root systems may suffer a transition shock during a changeover year; therefore, modern technologies such as drip or microsprinklers are less likely to be adopted for older groves (Shani 1976, 1979).

Model

The evidence and theory reviewed above were used in developing the following empirical model for irrigation technology adoption:

$$L = f(I, Q, A, E, O). \tag{1}$$

In this expression, L represents adoption level, I is water price, Q is a vector of variables representing quality of inputs used in the production process, including environmental effects and grove characteristics; A is a vector of variables measuring scale of operation and scarcity of inputs, both affecting on-farm operation decisions; E is a variable standing for human capital; and O is a variable representing the farm organization type.

It is hypothesized that a higher rate of adoption is likely to occur when water price is higher, when input quality is lower, and when inputs are relatively scarce. It is also hypothesized that scale of operation affects the level of adoption positively. A more supportive farm organization type is expected to increase adoption. Human capital can be measured using several variables including education, experience, and age. No a priori expectations are provided at this stage as to the effects of human capital variables.

Data and Empirical Specifications

The model was applied to a study of citrus groves in Israel and Gaza. The study sample included only owner-operated groves. Groves smaller than 2.5 ha were omitted from the sample on the assumption that their owners are part-time growers whose decisions might, therefore, be based on factors not relevant to this analysis. A total of 209 groves owned by *kibbutz*, *moshav*, and private owners were included in the final sample. These groves are from settlements in six regions (Hadera, Ra'anana, Rehovot, Lackhish, Negev, and Gaza). Questionnaires were completed between October 1986 and April 1987 and the data reported were for the 1987 crop year. The main variables include adoption dates of the irrigation technologies starting with the establishment of the grove; current percentage of land in various irrigation technologies; grove and grove operator characteristics; information on water quantity, quality, and cost; and land quality.

Irrigation technologies in common use were (in order by their introduction to the market): (*a*) traditional irrigation such as border and furrow, hereafter, furrow; (*b*) hand-moved sprinklers (aluminum pipes); (*c*) solid-set sprinklers above canopy; (*d*) drag-line sprinklers under canopy (plastic pipes); (*e*) solid-set sprinklers under canopy (plastic pipes); (*f*) low volume microsprinklers and microjets; and (*g*) drip irrigation. The first four, hereafter, "old," irrigation technologies are characterized by relatively smaller per-unit area investment costs than are the latter three. These last three technologies are characterized by more uniform water application, more efficient water use, and improved management flexibility, and will hereafter be identified as "the modern technologies." The performances of the modern technologies are quite similar. For example, Letey et al. suggested (using cotton as an example) a range of 70–85 CUC (Christiansen Uniformity Coefficient as a measure for uniformity of water application) for furrow and hand-moved sprinklers and a range of 85–90 CUC for the modern technologies. Summary costs for the various technologies are presented in appendix 1. More details on the technology characteristics and associated costs (for 1986) can be found in Dinar and Yaron. General information on sample size and current distribution of irrigation technologies by regions are presented in table 1.

Two groups of variables are used to represent adoption: (*a*) the percentage (share) of grove area currently equipped with modern irrigation technologies and (*b*) the time lag between the introduction of a given technology into the market and its adoption by the grower (speed of adoption). The estimated expressions are:

Table 1. Regional and Sample Information and Percent of Citrus Area Equipped with Different Irrigation Technologies in 1987, by Regions

	Region					
	Gaza	Negev	Lackhish	Rehovot	Ra'anana	Hadera
Citrus area (000 ha)	[a]	2.9	3.6	11.4	11.0	6.5
Sample area (ha)	375	1,873	633	1,030	1,210	759
Sample groves	44	57	21	28	25	34
Technology	Percent of area equipped with technology					
Furrow	50.3	0	0	0	0	0
Hand moved	0	0	0	0	0	0.7
Above canopy	0	0	0	0	2.3	7.9
Drag line	0	32.0	40.5	21.4	23.4	8.3
Solid set	5.6	5.4	28.9	27.8	35.9	42.5
Microsprinkler	44.1	7.0	17.7	48.6	34.3	38.2
Drip	0	45.6	12.0	2.3	4.1	2.4

[a] Regional data not available.
Note: ha = hectare.

(2)

$$P^m = f^1(I, Q^c, Q^s, Q^m, W, T^0, A^c, A^f, E, Y, O, R)$$

and

(3)

$$G = f^2(I, Q^c, Q^s, Q^m, W, T^0, A^c, A^f, E, Y, O, R).$$

P^m is the share of the grove area equipped with modern irrigation technologies. Two measurements were made for this variable: (*a*) share of area equipped with all modern technologies (solid-set sprinklers, microsprinklers, drip) and (*b*) share of area equipped only with drip irrigation.

Growers facing unfavorable growing conditions may react more promptly to the introduction of modern technologies. The variable G is speed of adoption (in terms of response time). It is defined as the time lag (years) between the appearance of a technology in the market and its adoption by a grower. G accounts for all irrigation technologies adopted in the grove by weighting each lag value associated with a given technology by the current area equipped with that technology. $G = \Sigma_k \phi_k (t_k - T_k)$, where ϕ_k is the portion of grove area currently equipped with the kth irrigation technology, t_k is the year in which the kth irrigation technology was first introduced into the grove, and T_k is the year it was first introduced into the market [assuming free access to this technology for all growers (Feder, Just, and Zilberman) and the same year for all regions]. The information for T_k was obtained from records provided by the Israel Extension Service, Division of Irrigation and Soil Field Service.

The variable I is the average cost of water from all sources at the gate of the grove. The variable Q^c is a measure for long-term trends of salt concentration in the irrigation water provided to the grove [ppm Cl]. A long-term data set for salt concentration in water supply for each grove (wells, regional water projects, etc.) during the period 1950–86 was used (TAHAL). As the first step in defining Q^c, linear equations were estimated for each grove: $a_i = \alpha_{0i} + \alpha_{1i} t$, where a_i is level of salt concentration in the irrigation water; the intercept α_{0i} $(-\infty < \alpha_{0i} < +\infty)$ is the initial water salinity, and the slope α_{1i} (≥ 0) is the grove's long-term salinity trend. The index i stands for grove i and t is time. Groves with saline irrigation water will have high intercept and slope values. The variable Q^c was calculated as $Q^c = \beta_0 \alpha_0 + \beta_1 \alpha_1$ using a principal components analysis where β_0 and β_1 are the eigenvalues (.707 and .708, respectively) of the first principal component vector, which explained 91% of the standardized variance between the intercept and the slope of the long-term salinity trend, respectively. The variable Q^c is expected to be positively correlated with adoption level and negatively correlated with response time. In other words, growers with poor water quality are expected to use more modern irrigation technologies and to be early adopters of these technologies.

Q^s stands for land quality. Land quality has many dimensions. In this study soil type was used as a surrogate for moisture-holding capacity[1] representing land quality. The soil type that dominated most of a grove's area was assumed to represent that grove (Israel Extension Service, Division of Irrigation and Soil Field Service). Soil types were ranked according to their moisture-holding capacity (Doorenbos and Pruitt). Soil types considered were (from higher to lower moisture-holding capacity): heavy, loess, semiheavy, light, and sandy. Typical values for available moisture-holding capacity, according to Israelsen and Hansen, are 21%, 18%, 14%, 9%, and 6%, respectively, for the above soil types.

The variable Q^m can be viewed as a grove's resistance to poor input quality and is represented by the share of sensitive rootstock in the grove. *Hushchash* and *Limeta* are typical rootstock found in the sample. The latter is more sensitive to poor soil and water quality, and the percentage of the grove area with this sensitive rootstock was used to calculate the value of Q^m. Groves with a higher percentage of sensitive rootstock are more likely to adopt modern irrigation technologies and are also more likely to have a shorter response time.

W is per-land-unit water quota allotted to the farm [cubic meters/hectare (m^3/ha)]; it is expected to be negatively correlated with level of adoption and positively correlated with response time. The variable T^0 is the age of the grove, measured as the year in which the oldest existing plot was planted. Younger groves are likely to have more modern technologies and shorter response time than older groves.

A^c and A^f are grove and farm area [ha], respectively. Both tend to be positively correlated with level of adoption and negatively correlated with response time. The variable E represents the grower's years of citrus-growing experience. This specific human capital variable is expected to be negatively correlated with the level of adoption and negatively correlated with the response time. There are two possible reasons for such relationships. One is that a grower with longer experience using an old technology is likely to have developed solutions to irrigation problems while applying that technology and is therefore less likely to adopt a modern technology (Stefanou and Saxena). The second reason is that experience is usually correlated with the decision maker's age, which in turn is negatively correlated with level of adoption. Rahm and Huffman, however, concluded that the net effect of experience on adoption is a priori uncertain.

The long-term average yield (Y) measured in metric ton/ha is generally representative of management level of the grove, although it also can be correlated with other variables such as water quality and grove sensitivity. Including yield in the same equation with water quality and grove sensitivity can therefore lead to multicollinearity problems. However, if all other variables are constant, a grower having a grove with higher long-term average yield is more likely to adopt modern technologies and to do so within a shorter response time.

O is a dummy variable representing farm organization type. Higher levels of organizational support (decreasing from *kibbutz* to private settlements) are expected to be correlated with a higher level of adoption and a shorter response time. R is a dummy regional variable accounting for influence of weather conditions and other regional characteristics such as extension service influence. Its relationship to adoption is not a priori known. Sandy soil, privately owned groves, and the Hadera region were used in the analysis as bench marks for the land quality, organization type, and regional dummy variables, respectively. Descriptive statistics for the variables included in the analysis are presented in table 2.

Results

General information on the sample and current proportions of irrigation technologies by region are presented in table 1. Modern technologies currently account for 50% to 92% of the grove area in the regions considered. It should be noted that drip irrigation is not present in the Gaza region (as of 1987). A typical grove is equipped with more than one irrigation technology. Different plots in a grove might have disparate combinations of soil, rootstock, and even water quality. In practice, each plot is considered as a separate decision unit. The existing data, however, permit analysis at the grove level only; therefore, percentages of area equipped with various technologies are used. OLS is appropriate in this case since the dependent variables are continuous and the share of modern irrigation technologies (solid-set

---

[1] Moisture-holding capacity is the maximum available moisture to the crop in a given depth of soil.

sprinklers, microsprinklers, drip) is always greater than zero. The estimate of the share of modern technology therefore should not be biased.

Aggregations were made in order to improve the significance level of the estimated coefficients of the dummy variables for soil and regional conditions. Thus, soil types were combined as follows: heavy soils (including heavy and loess), light soils (including semiheavy and light), and sandy soil; regions also were combined to include: (*a*) Gaza, (*b*) southern regions (Negev and Lackhish), (*c*) central regions (Rehovot and Ra'anana), and (*d*) Hadera as the northern region. Linear and log–log functional forms of the adoption equations were estimated. The results for the log–log estimates were relatively poor; therefore, only the linear estimates are presented in table 3.

In table 3 estimate 1 is for the dependent variable share of modern irrigation technologies, and estimate 2 is for the share of drip only. Both include dummy variables for land quality, organization type, and regional conditions (R^2 was increased from .64 to .79 and from .53 to .71 for modern and drip shares, respectively, when these dummies were included). Estimate 3 is for the response time. Results for response time including the dummy variables suggest that land quality, organization type, and regional conditions are not significant. Thus, the estimate for response time including these dummies is not presented.

Forty-three percent to 79% of the variance of the dependent variables can be explained by differences in water cost, in quality and scarcity of inputs, in human capital, in organization type, and unspecified regional conditions. All *F*-statistics show that the variables in the regression equations jointly exert a significant effect on the dependent variable. In general, the estimated coefficients are significant and behave as expected for almost all the regression equations. Only the coefficient for settlement area in regression equations (1) and (2) and the variable for experience in equation (2) have signs opposite of what was expected. The results show that with all other variables constant, *kibbutz* settlements have larger shares of all modern technologies and especially drip on their groves and are adopting modern technologies faster than in the *moshav*, or privately owned groves. Similarly, southern regions have larger shares of modern irrigation technologies and also have adopted modern technologies faster than northern regions. One possible explanation for this result is less extreme weather conditions in the central and northern parts of the study area. High temperatures are more likely to be offset by modern irrigation technologies which have better control and flexibility. Land quality was always significant. As in previous studies by Caswell and Zilberman (1985); Lichtenberg; and Negri and Brooks, our results show that modern technologies are more likely to be adopted on light soils than on heavy soils.

Table 2. Descriptive Statistics for Variables in the Analysis

Variable	Mean	Standard Deviation
Drip share (fraction)	.20	.33
Modern technologies share (fraction)	.50	.43
Response time (years)	10.1	3.78
Experience (years)	18.0	11.31
Long-term average yield (ton/ha)	49.0	17.7
Water allotment (m³/ha)	5,823	2,394.8
Long-term water salinity (ppm Cl)	226.1	321.0
Rootstock sensitivity (fraction)	.20	.36
Farm area (ha)	243.6	211.8
Grove area (ha)	28.7	22.25
Grove's age (years)	56.5	10.32
Water price ($/m³)	.10	.046

All coefficients in the equation for share of drip have greater values than those in the equation for share of all modern technologies. This finding is reasonable given that the total percentage of grove area equipped with drip irrigation is less than the total percentage of area equipped with all modern irrigation technologies, including drip. In many groves drip replaces other modern technologies (especially solid-set sprinklers) as well as old irrigation technologies. Consequently, the marginal effect of the explanatory variables on the adoption of drip is expected to be greater.

The marginal effects of input quality and scarcity on the combined shares of all modern technologies and of drip are indicated by the estimated coefficients in table 3. Using the mean values of these variables as a starting point, the marginal effect of land quality and water allotment is 10 to 50 times greater than that of water quality or grove sensitivity. The marginal effect of water price in the case of drip is similar to that of land quality.

Table 3. Estimates of Equations for Adoption of Modern Irrigation Technologies

Equation Dependent Variable	(1) Share of Modern Technologies	(2)[a] Share of Drip	(3) Response Time
Intercept	.506	−.236	.743
	(.89)	(−.66)	(.05)
Water quality (ppm Cl)	$5.10 \cdot 10^{-6}$	$7.36 \cdot 10^{-5}$	$-2.41 \cdot 10^{-3}$
	(1.81)	(1.83)	(−1.72)
Water allotment (m^3/ha)	$-2.12 \cdot 10^{-4}$	$-2.81 \cdot 10^{-4}$	.0258
	(−2.04)	(−1.04)	(2.98)
Grove sensitivity (fraction)	.211	.288	−2.48
	(3.35)	(1.81)	(−2.03)
Grove age (years)	−.0038	−.0059	.113
	(−1.67)	(−1.28)	(3.68)
Grove area (ha)	$1.42 \cdot 10^{-4}$	$1.47 \cdot 10^{-4}$	−.017
	(1.35)	(1.21)	(−2.30)
Settlement area (ha)	$-3.80 \cdot 10^{-6}$	$-2.75 \cdot 10^{-5}$	$-5.70 \cdot 10^{-4}$
	(−.22)	(−1.28)	(−.53)
Experience (years)	−.0047	.0042	.251
	(−2.36)	(1.57)	(1.61)
Average yield (metric tons/ha)	.0086	.041	−6.95
	(1.29)	(2.35)	(−6.26)
Water price (\$/m^3)	.16	1.49	−2.42
	(2.10)	(1.64)	(−3.39)
Soil			
Heavy	.145	−.0055	
	(1.19)	(−1.07)	
Light	.288	.163	
	(2.31)	(2.12)	
Organization			
Kibbutz	.367	.352	
	(2.05)	(2.06)	
Moshav	.281	.163	
	(1.67)	(1.52)	
Region			
Gaza	−.134		
	(−.43)		
South	.272	.125	
	(1.97)	(2.38)	
Central	.206	.062	
	(1.44)	(1.70)	
R^2	.79	.71	.43
F	32.3	16.5	18.1
d.f.	171	145	183

[a] Not including Gaza.
Note: *t*-values are in parentheses.

Policy Implications

In many instances it is in the interest of a local government or a central authority to improve irrigation performances. For example, in the San Joaquin Valley of California, irrigated agriculture is affected by severe arid conditions on the one hand, and in turn, affects environmental conditions by aggravating drainage problems on the other. Interrelated problems of aridity, salinity, and poor drainage are present in many sites around the world.

Policy makers often consider incentives to improve irrigation performance, conserve irrigation water, and reduce drainage volumes. Modern technologies provide better irrigation uniformity and, therefore, promote reductions in total applied water and less deep percolation. For example, according to Meyer, in a long-term regional citrus irrigation experiment at the McKellar Project in Tulare County, California, it was found that irrigation requirements varied significantly among drip, sprinklers, and furrow with recommended values for water application of 8,128, 8,890, and 9,906 m^3/ha, respectively. A transition from furrow to drip may save 18% of the water consumed by citrus in this region and further reduce the amount of drainage water.

Field data for citrus groves from the southern San Joaquin Valley for the period 1977–81 (Vaux, Handley, and Giboney) show average water applications of 7,051, 7,475, 7,943 and 8,171 m^3/ha for drip, furrow with tailwater reuse (TWR), sprinklers, and furrow without TWR, respectively.[2] These results suggest savings from 5.6% to 13.7% in this region with drip versus furrow without and with TWR, respectively. The data in appendix 1 for Israel similarly indicate up to a 22% saving with drip versus furrow technology. The values for water savings shown above may provide an incentive to a transition from old to modern technologies, although savings can be higher or lower depending on site and local conditions.

Although a transition from old to modern irrigation technologies might be economically profitable for growers and society, additional factors will affect the feasibility of a policy to encourage this transition. The estimated coefficients [equation (1) in table 3] are used to illustrate the tradeoffs among policy variables and combinations of input quality variables which affect adoption of modern irrigation technologies.

The policy variables used in this section are water price and water allotment to the farm; the quality variable is soil type. The values for these variables are based on the range observed in the data (table 2). Other variables in the estimated expression are held constant at their mean values and are added to the constant term. The dummy variables for organization type and region are held constant at bench mark values. The results for adoption levels of modern irrigation technologies in regions with heavy and light soils are presented in table 4.

Table 4. Tradeoff between Water Price and Water Allotment to Achieve Various Levels of Irrigation Technology Adoption

Water Quota to Farm (m^3/ha)	Soil Type					
	Heavy			Light		
	Water Price (\$/m^3)			Water Price (\$/m^3)		
	.05	.10	.20	.05	.10	.20
4,000	.208	.216	.232	.352	.360	.376
5,000	.187	.195	.211	.331	.339	.355
6,000	.166	.174	.190	.310	.318	.334
7,000	.144	.152	.168	.288	.296	.312

Water price and water quota rates can be substituted to achieve similar adoption levels (table 4). For example, with heavy soil either a water price of \$.05/m^3 and a water quota of 6,000 m^3/ha or a water price of \$.20/m^3 and a quota of 7,000 m^3/ha will achieve a predicted 16% to 17% conversion of the regional citrus area to modern irrigation technologies.

Conclusions

This study examined the effect of input price, quality and scarcity of inputs, geographical conditions, and other variables on the adoption of modern irrigation technologies by Israeli citrus growers. On-farm data were used to examine hypotheses established in previous theoretical and empirical studies. The nature of the data permitted accounting for relative effects of different variables which were used separately in previous studies.

A grower's speed of adoption was used as an additional dependent variable utilizing the same set of variables used to explain other measurements of adoption such as the shares of modern technologies and drip irrigation. The speed of adoption results have implications for irrigation technology diffusion in response to price policies or changes in water allotments.

The results for the two measurements of adoption in terms of shares of technologies demonstrate the importance of using separate indices for drip irrigation and for the package of drip, microsprinklers, and solid-set sprinklers. Citrus groves with a variety of conditions may be equipped with a combination of technologies. The technology choice is not only between drip and sprinklers but also among combinations of modern versus old irrigation technologies. These results confirm that a combination of economic and geographic charac-

---

[2] The study includes 1,710 plots for various crops, including citrus. The overall conclusion from this study is that "in the aggregate no technology performs or is managed with superior consistency in the field."

teristics influences adoption of modern irrigation technologies.

Adoption of technologies is a dynamic process involving individual growers. Therefore, empirical studies ideally should use time-series data for individuals, but this is very difficult to find. Among the limitations of the present cross-sectionally based study was the lack of grove-level time-series information on cost of technologies, prices of major inputs and outputs, water application rates, and crop yields. Nevertheless, the results provide insight into the process where input quality and human capital factors as well as water pricing and allocation policies can influence adoption of modern irrigation technologies.

[Received September 1988; final revision received May 1990.]

References

Caswell, M., and D. Zilberman. "The Choices of Irrigation Technologies in California." *Amer. J. Agr. Econ.* 67(1985):224–34.

———. "The Effects of Well Depth and Land Quality on the Choice of Irrigation Technology." *Amer. J. Agr. Econ.* 68(1986):798–811.

Dinar, A., and D. Yaron. "Adoption of New Irrigation Technologies in Citrus: Process Description and the Influence of Inputs Scarcity and Quality." Final Report, TATEC-Patterns of Agricultural Technology Exchange and Cooperation in Similar Ecosystem: The Case of Egypt and Israel, May 1988.

Dinar, A., J. Letey, and K. C. Knapp. "Economic Evaluation of Salinity, Drainage and Non-uniformity of Infiltrated Irrigation Water." *Agr. Water Manage.* 10(1985):221–33.

Doorenbos, J., and W. Pruitt. "Crop Water Requirements." Irrigation and Drainage Paper 24, Food and Agriculture Organization of the United Nations (FAO). Rome, Italy, 1984.

Feder, G. "Farm Size, Risk Aversion and the Adoption of New Technology under Uncertainty." *Oxford Econ. Pap.* 32(1980):263–83.

Feder, G., R. E. Just, and D. Zilberman. "Adoption of Agricultural Innovations in Developing Countries, A Survey." *Econ. Develop. and Cultural Change* 33(1985):255–98.

Feinerman, E., and D. Yaron. "Adoption of Drip Irrigation in Cotton: The Case of Kibbutz Cotton Growers in Israel." *Oxford Agrar. Pap.* (1990), in press.

Feinerman, E., J. Letey, and H. J. Vaux, Jr. "The Economics of Irrigation With Nonuniform Infiltration." *Water Resour. Res.* 19(1983):1410–14.

Hazan, Z. Chief Agricultural Officer, Ministry of Agriculture, The Gaza Civilian Administration. Personal communication, March 1990.

Housmann, J. A. "Individual Discount Rates and the Purchase and Utilization of Energy Using Durables." *Bell J. Econ. Manage.* Spring(1979):33–54.

Huffman, W. E. "Allocative Efficiency: The Role of Human Capital." *Quart. J. Econ.* 91(1977):59–79.

Israel Extension Service, Division of Irrigation and Soil Field Service. "Periodical Irrigation and Fertilization Recommendations for Citrus." Hakiria, Tel-Aviv, Israel. Various years.

Israelsen, O. W., and V. E. Hansen. *Irrigation Principles and Practices.* New York: John Wiley and Sons, 1979.

Jarvis, L. S. "Predicting the Diffusion of Improved Pastures in Uruguay." *Amer. J. Agr. Econ.* 63(1981):495–502.

Kislev, Y., and N. Shchori-Bachrach. "The Process of an Innovation Cycle." *Amer. J. Agr. Econ.* 55(1973):28–37.

Letey, J., A. Dinar, C. Woodring, and J. Oster. "An Economic Analysis of Irrigation Systems." *Irrigation Sci.* 11(1990):37–43.

Lichtenberg, E. "Land Quality, Irrigation Development, and Cropping Patterns in the Northern High Plains." *Amer. J. Agr. Econ.* 71(1989):187–94.

Messer, J. "International Development and Trends in Water Reuse." In *Water Reuse,* ed., E. J. Middlebrooks. Ann Arbor MI: Ann Arbor Science Publishers, 1982.

Meyer, J. L. Irrigation Specialist, University of California, Cooperative Extension, Department of Soil and Environmental Sciences, Riverside. Personal Communication, March 1990.

Molcho, S., and E. Katz. "Personal and Other Factors in the Adoption of Agricultural Innovations in the Kibbutz and the Old-established Moshav." In *Agricultural Extension,* eds., S. Molcho and M. Gitlin. Jerusalem: Keter Publishing House, 1970.

Negri, D. H., and D. H. Brooks. "Determinants of Irrigation Technology Choice." *West. J. Agr. Econ.* 15(1990):213–223.

Putler, D. S., and D. Zilberman. "Computer Use in Agriculture: Evidence from Tulare County, California." *Amer. J. Agr. Econ.* 70(1988):790–802.

Rahm, M. R., and W. E. Huffman. "The Adoption of Reduced Tillage: The Role of Human Capital and Other Variables." *Amer. J. Agr. Econ.* 66(1984):405–13.

Ravid, N. Head, Department of Citrus, Israel Extension Service, Hakiria Tel-Aviv, Israel. Personal Communication, March 1990.

Rosenman, R. E. "Conservation Choice as an Endogenous Dummy Variable." Paper presented at the annual meetings of the Amer. Agr. Econ. Assoc., Ames IA. 4–7 August 1985.

Shani, M. *Drip Irrigation—Practices and Equipment.* Ministry of Agriculture. The Extension Service. 2nd ed., 1976.

———. *Irrigation with Micro Sprinklers—Equipment and*

Practices. Ministry of Agriculture. The Extension Service, 1979.

Stefanou, S. E., and S. Saxena. "Education, Experience, and Allocative Efficiency: A Dual Approach." *Amer. J. Agr. Econ.* 70(1988):338–45.

TAHAL. Israel Water Planning Company Ltd., Tel-Aviv. The Hydrology Division. Unpublished data, 1987.

Vaux, H. J., Jr., D. F. Handley, and P. M. Giboney. "An Assessment of Irrigation Technology Performance in the Southern San Joaquin Valley of California." *Water Resour. Res.* 26(1990):35–41.

Appendix

Table A1. Comparison of Various Irrigation Technology Costs, Recommended Applied Water, and Actual Citrus Area by Technology, 1990

Technology	Investment Cost	Maintenance Cost	Operational[a] Cost	Total[b] Annual Cost	Recommended Applied Water[c]	Area[d]
	[$/ha]				[m³/ha]	[ha]
Furrow	2,100	10	539	763	9,000	3,500
Hand moved	1,900	113	650	1,379	8,500[e]	0
Above canopy	3,630	136	65	1,116	8,000	1,000
Drag line	2,600	124	387	1,157	8,500	2,000
Solid set	3,500	255	74	2,146	7,000	25,000[f]
Microjet	3,380	151	98	1,172	7,000	
Microsprinkler	2,420	136	74	872	7,000	
Drip	1,710	148	61	737	7,000	6,000

Note: Prices are February 1986 dollars. Costs are based on Dinar and Yaron.

[a] Includes machinery, labor, and energy.

[b] Uses a 10% interest rate for depreciation.

[c] Water application rates are based on average recommendations. Values can vary with citrus variety, grove age, soil type, and region (Ravid). For example, irrigation of citrus with microsprinklers in Gaza on sandy soil may consume 9,000 m³/ha (Hazan). Coefficient for furrow (practiced in 1990 only in Gaza) was provided by Hazan. Coefficients for the other technologies were provided by Ravid.

[d] Area equipped with furrow was provided by Hazan. Areas equipped with the other technologies were provided by Ravid.

[e] This technology was not in use for citrus groves in 1990. Therefore, this value is used from previous years when hand-moved sprinkling was practiced.

[f] Aggregated data only were available for the solid-set, microjet, and microsprinkler technologies.