AgEcon SEARCH
RESEARCH IN AGRICULTURAL & APPLIED ECONOMICS

The World's Largest Open Access Agricultural & Applied Economics Digital Library

This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.

Help ensure our sustainability.

Give to AgEcon Search

AgEcon Search
http://ageconsearch.umn.edu
aesearch@umn.edu

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

No endorsement of AgEcon Search or its fundraising activities by the author(s) of the following work or their employer(s) is intended or implied.

Agricultural Economics, 6 (1992) 315–332
Elsevier Science Publishers B.V., Amsterdam

Adoption and abandonment of irrigation technologies

Ariel Dinar
Department of Agricultural Economics, University of California and USDA-ERS, Davis, CA, USA

and Dan Yaron
Department of Agricultural Economics and Management, The Hebrew University of Jerusalem, Rehovot 76100, Israel

(Accepted 20 March 1991)

ABSTRACT

Dinar, A. and Yaron, D., 1992. Adoption and abandonment of irrigation technologies. *Agric. Econ.,* 6: 315–332.

Adoption and abandonment processes are analyzed for seven irrigation technologies. A procedure is developed to estimate the technology cycle and applied to data available for citrus groves in several regions of Israel, and Gaza. The technology cycle was used to estimate diffusion-abandonment patterns for several irrigation technologies that have been abandoned. Results suggest that the technology cycle is unique to each technology and similar in length for all regions. Results predict the year of full abandonment of each technology. For modern technologies still in the diffusion phase, a logistic equation was fitted to the aggregated data. Results suggest that diffusion is significantly affected by economic variables such as water price, crop yield price, and subsidy for irrigation equipment. Use of the estimated equations for policy purposes suggest that water price and subsidy for irrigation equipment can be used to control the diffusion process (speed and ceiling) of the irrigation technologies.

INTRODUCTION

The diffusion of innovations has long been a major topic in the context of technological change. Most of the empirical economic studies on diffu-

Correspondence to: A. Dinar, Department of Agricultural Economics, University of California, Davis, CA 95616, U.S.A.

0169-5150/92/$05.00 © 1992 – Elsevier Science Publishers B.V. All rights reserved

sion of technologies have estimated rates of adoption and levels of adoption until the stage when the process reaches its ceiling (e.g., Jarvis, 1981; Jansen, Walker and Barker, 1990). Less attention has been devoted to the stage when the innovation is abandoned, which occurs at least as frequently in the history of technological changes. A discontinuance of technology can be the result of technological substitution (Fisher and Pry, 1971; Rogers, 1983; Cameron and Metcalfe, 1987) which creates technology cycles.

In the development of new technologies it is essential for the developer, or the policy maker, to estimate the expected life span of the technology in order to analyze the effects of possible policy variables on the resulting number of users of that technology (or any other measure for intensity of use). Several studies have recognized the importance of irrigation technologies in the process of agricultural development (Hayami and Ruttan, 1971; Kulshreshtha, 1989). The economic literature on irrigation technology diffusion has generally provided information on diffusion of one or at most two technologies (Fishelson and Rymon, 1989; Casterline, Dinar and Zilberman, 1989). Less attention has been devoted to the abandonment phase of the technologies. This is probably due to lack of information on use of various technologies over time.

The purpose of this paper is to extend the existing literature by depicting and estimating the diffusion-abandonment processes of several irrigation technologies. The next section provides a conceptual framework for the analysis which includes both the procedure for estimating technology cycles and the framework for estimating diffusion-abandonment and diffusion curves for several technologies. This framework is applied to survey data from citrus groves in Israel. As compared to previous studies, this data base addresses seven irrigation technologies. The estimates for the diffusion curves are used to demonstrate and estimate policy effects on the diffusion of irrigation technologies.

CONCEPTUAL FRAMEWORK

The introduction of any technology can be described as composed of two phases: in the first phase, the technology is introduced to an increased number of users (or any measure of use, such as number of acres). This phase is generally defined in the literature as the diffusion of the technology. The second phase is characterized by declining use of that technology. The economic literature has concentrated mainly on estimating diffusion curves for technologies (e.g., Griliches, 1960; Jarvis, 1981). However, it is also important for policy makers to know the rate and time at which a technology will be abandoned. The analysis provided in this section distinguishes (using the terminology suggested earlier) between two groups of technologies: (1) technologies that are in a process of abandonment or have already been abandoned, and (2) technologies that are still in the diffusion process.

For the first group of technologies, a procedure is suggested to estimate the technology cycle and is applied to data for citrus groves. The technology cycle provides data used to estimate a quadratic expression of share of users for a given technology over time (a diffusion-abandonment pattern), which is applied to estimate the time of a complete discontinuance of that technology. For the second group of technologies diffusion logistic curves are estimated. Crop yield price, water price, and government subsidy for irrigation equipment are used to explain diffusion rates.

A procedure for estimating technology cycles

The term 'innovation cycle' in agriculture was used by Kislev and Shchori-Bachrach (1973). They estimated the effects of different profiles of adopters on the diffusion rate and ceiling for agricultural use of plastic sheeting, without, however, estimating the length of the innovation cycle. Several studies (Coughenour, 1961; Bishop and Coughenour, 1964; Deutschmann and Hevens, 1965) investigated the reasons for discontinuing innovations, but no innovation cycle was estimated. Easingwood (1988) estimated product lifespan patterns for new industrial products. His model provides an estimate for the overall life of a given technology from the first day of its appearance in the market until its final disappearance. Although the concept of technology cycle was implicitly included in Easingwood (1988), no use or estimate was provided.

Estimation of diffusion and abandonment processes for technologies used in the distant past may face problems of reliable data since documentation on the number (or share) of users may not be complete for the entire period. This may partially explain past difficulties in estimating technology cycles. The current study is fortunate to have data that allows detection of the diffusion-abandonment process. Several data points exist: (1) the number of users (or acres) and time (year) when the technology was first introduced, (2) present information on use of the technology, and (3) information is also available on the number of new adopters during the diffusion phase only but not during the abandonment phase.

Diffusion and abandonment of a given technology in the absence of a complete data set for the stage of abandonment can be described using the concept of technology cycle that provides the rate at which technologies are being replaced. A technology cycle is defined here as the time period between the adoption of a particular technology by a decision maker and its abandonment or replacement by another technology. This concept has been used broadly in models of equipment replacement (e.g., Rifas, 1957, p. 67) that suggest replacement patterns for equipment used by identical producers. Therefore, the technology cycle hereafter presented is not a behavioral model (such as the model in Kislev and Shchori-Bachrach, 1973), but rather, a procedure to fit a curve to incomplete time series data. In doing so, one assumes that each technology is associated with a given life span (cycle) that does not change over time or as a result of market events. This is a simplifying assumption since technology cycles may be influenced by competing technologies, and prices, although, there are circumstances when this is not necessarily true (Dinar and Zilberman, 1991). Therefore, the estimates here can provide an upper bound to the technology cycle.

Let $t = t_0, \ldots, t_\tau, \ldots, t_T$ be the analyzed time period where t_0 and t_τ are the first and last years with observed number of adopters, and t_T is the last year in the sample for which the actual number of users of a particular technology is known (notice that $t_T \geqslant t_\tau$).

N_{t_T} is the observed number of users of the technology at time t_T, and n_t is the number of new adopters in year t. The variable $\boldsymbol{n}_t$ is defined as the cumulative number of adopters in year t, assuming (at this stage) no discontinuance or abandonment of that technology (pure accumulation).

Then:

$$\boldsymbol{n}_t = \sum_{j=t_0}^{t} n_j \tag{1}$$

This definition of $\boldsymbol{n}_t$ accounts for the cumulative number of possible users as it appears in the data set. Since the above expression does not take into account the number of growers abandoning the technology, the value for $\boldsymbol{n}_t$ at year t is not in agreement with the observed value for users of the technology in year t, and therefore:

$$N_{t_T} \leqslant \boldsymbol{n}_{t_T} \tag{2}$$

and

$$\boldsymbol{n}_{t_\tau} \leqslant \boldsymbol{n}_{t_T} \tag{3}$$

The variable N_t° is the estimated number of users of the technology at year t that is implicitly expressed as:

$$N_t^\circ = f\left[n_{t_0}, \sum_{j=t_0}^{t} n_j, z\right] \tag{4}$$

where z is the technology cycle (years).

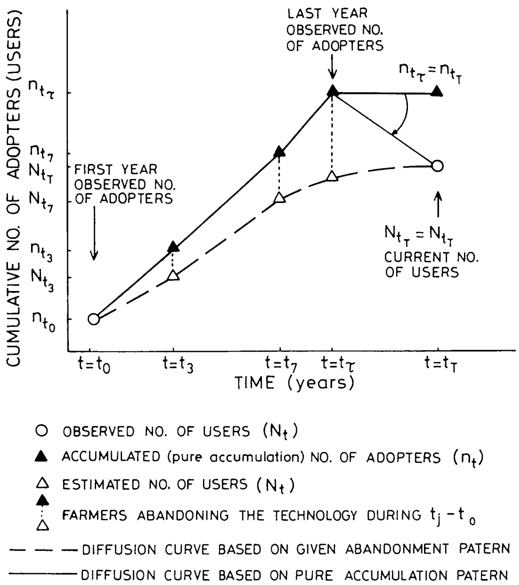

Fig. 1. Scheme for the estimation procedure of the technology cycle.

More specifically, N_t° can be estimated as follows (see also Fig. 1):

$$N_t^\circ = \begin{cases} n_{t_0} & \text{for} \quad t = t_0 \\ N_{t-1}^\circ + n_t - \xi_t & \text{for} \quad t_0 < t < t_T \\ N_{t-1}^\circ - \xi_t & \text{for} \quad t = t_T \end{cases} \tag{5}$$

and

$$\xi_t = \begin{cases} 0 & \text{for} \quad t - t_0 < z \\ 0 & \text{for} \quad n_{t-z} = 0 \\ n_{t-z} & \text{for} \quad t - t_0 \geqslant z \end{cases} \tag{6}$$

where ξ_t is the number of farmers abandoning the technology at year t. The estimated technology cycle (z^*) is then the value for the technology cycle that minimizes the difference between the observed and calculated number of users at year T:

$$z^* = z \to \left\{ \min_z \left| N_{t_T}^\circ - N_{t_T} \right| \right\} \tag{7}$$

As a first step, technology cycles are estimated for each irrigation technology in every region using the system consisted of (4)–(7). This is done using a simulation program (simulated values for drag-line are presented in Fig. 2) and a reasonable range of initial values for z. The chosen value (z^*) is the one that meets the criteria of equation (7).

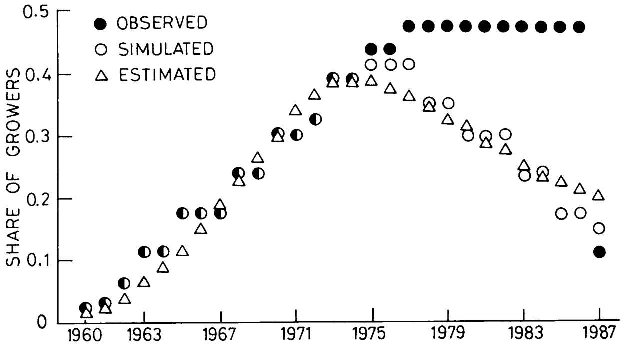

Fig. 2. Observed, simulated and estimated values for the diffusion of drag-line sprinklers in Hadera region.

To demonstrate the use of the technology cycle for creating the data needed to estimate a diffusion-abandonment curve for a given technology, assume for example, data for a 7-year period, and a cycle of 4 years. The number of new adopters each year is 5, 7, 4, 3, 4, 3, 0, over the period of the 7 years. The actual number of users will therefore be 5, 12, 16, 19, 18 ($19 + 4 - 5$), 14 ($18 + 3 - 7$), 11 ($14 + 0 - 3$). Notice that for the first 4 years, the technology was in a phase of diffusion and then for 3 years it is in an abandonment process.

Diffusion-abandonment curves for irrigation technologies that have been abandoned

For technologies in the abandonment phase, a diffusion curve is developed using the initial number of adopters and the estimated technology cycle, z^*. The observed pattern for these technologies displays a quadratic curve over time (Fig. 2). The quadratic functional form to be estimated for that process is:

$$N_t + t/\left[b_1 t^2 + b_2 t + b_3\right] \tag{8}$$

In this expression N_t is the cumulative share of adopters by year t. The index t was normalized by setting the first year of the diffusion at 1. b_1, b_2, and b_3 are the estimated coefficients. First-order conditions with respect to t provide the estimate for the year (t^*) in which the ceiling was reached:

$$t^* = (b_3/b_2)^{1/2} \tag{9}$$

Substituting t^* into the quadratic diffusion curve (8) yields the estimated ceiling, N_{t^*}. For $t > t^*$ the diffusion process is negative, meaning that the technology is being abandoned. For technologies that are still in a process of abandonment, the year of complete abandonment can be estimated by solving equation (8) with the estimated values for the b_i's, and setting N_t to be zero.

Effect of input and output prices on the diffusion of modern irrigation technologies

A number of studies have recognized that diffusion of a technology could be affected by the product price and the profitability expected to result from the technology. Griliches (1960) showed that the rate at which growers accept a new agricultural technology depends, among other things, on the magnitude of the profit to be realized from the changeover. Mansfield (1963) showed that diffusion rates of new technologies in several industries were positively related to the profitability of those technologies. Jarvis (1981) showed that both the rate and the extent of diffusion for new technologies were positively related to the profitability of those technologies. Using a normative model, Dinar and Letey (1989) demonstrated the positive combined effects of charges for irrigation water and capital subsidies for irrigation technologies on the economics of technology selection under various limiting environmental conditions. Theoretical and empirical evidence cited in Feder, Just and Zilberman (1985) and in Thirtle and Ruttan (1987), provides the basis to develop an empirical model to estimate effects of output prices and input costs on the diffusion of technologies. Long-term investment decisions such as in irrigation equipment are based on past and future price expectations for inputs and output. For the purpose of our analysis assume that only past prices of input and output (in year $t-\boldsymbol{t}$) affect the decision to invest in irrigation equipment.

This section demonstrates the use of economic variables to estimate diffusion curves. These variables represent crop yield price, water price, and subsidies provided by the government for the investment in irrigation technologies. (The model is applied to technologies that are still in the diffusion phase.)

The basic logistic equation for the diffusion process is:

$$N_t = d_1/\left[1+\exp(-d_2-d_3 t)\right] \tag{10}$$

where d_3, which is the rate of diffusion, is assumed to be a function of crop profitability, water price, and the subsidy for the investment in the technology (capital cost). By expressing d_3 as a linear function of these variables ($d_3 = \psi_0 + \psi_3 P_{t-\boldsymbol{t}} + \psi_4 P^{\mathrm{W}}_{t-\boldsymbol{t}} + \psi_5 S_{t-\boldsymbol{t}}$), the basic logistic equation becomes (Jarvis, 1981):

$$N_t = d_1'/\left[1+\exp\left(-d_2' - \psi_0 t - \psi_3 t P_{t-\boldsymbol{t}} - \psi_4 t P^{\mathrm{W}}_{t-\boldsymbol{t}} - \psi_5 t S_{t-\boldsymbol{t}}\right)\right] \tag{11}$$

where P_{t-t} is a variable measuring crop profitability, P^{W}_{t-t} is water price, and S_{t-t} is a variable measuring subsidy level for the capital cost of the technology in year *t-t*.

DATA AND EMPIRICAL SPECIFICATIONS

The models presented earlier were applied to data from a study of citrus groves in Israel. The study sample includes only groves which are owner-operated, and are greater than 2.5 ha (1 ha = 2.5 acres or 10 dunams). Excluded are groves operated either by cultivation companies on the basis of fixed payment, or by part-time operators [1]. These kinds of operators were observed to be motivated by economic considerations extremely different than full time owner operators (e.g., Guttman and Haruvi, 1986; Feder et al., 1988). A total of 209 groves owned by *kibbutz* (collective settlement), *moshav* (cooperative settlement), and private owners were sampled. These groves are from settlements in six regions (from north to south: Hadera, Ra'anana, Rehovot, Lackish, Negev and Gaza). The sampled area accounts for 16% of the total citrus area in Israel (Table 1). Questionnaires were completed during the course of interviews conducted with growers between October 1986 and April 1987. General information on sample size and current distribution of irrigation technologies by regions is presented in Table 1.

Irrigation technologies in common use during the study period were (in order of their introduction to the market): (1) traditional irrigation such as border and furrow, (2) hand-moved sprinklers (aluminum pipes), (3) solid set sprinkers above canopy (hereafter referred to as 'above-canopy'), (4) drag-line sprinklers under canopy (plastic pipes), (5) solid-set sprinklers under canopy (plastic pipes), (6) low volume micro-sprinklers and micro-jets, and (7) drip irrigation. The first four irrigation technologies have been abandoned by farmers in most of the regions. The later three technologies are still in a process of diffusion in most of the regions. These three technologies will be identified hereafter as 'the modern technologies'. Additional information with regard to the data, as well as detailed technology characteristics and associated costs, can be found in Dinar and Yaron (1988). Information regarding number of groves, and adoption periods for various technologies by region is presented in Table 2.

---

[1] It should be noted that the estimated share of these groves was 40% of the total area, but their share in production was less than 15% due to bad maintenance. Also, many of these groves went out of production atfer 1987 (N. Ravid, Head, Ext. Serv. Dep. Citrus, Hakiria Tel-Aviv, personal communication, 1990).

TABLE 1

Characteristics of sample citrus farms, 1987, by region

	Region					
	Gaza	Negev	Lackish	Rehovot	Ra'anana	Hadera
Citrus area (1000 ha)	[a]	2.9	3.6	11.4	11.0	6.5
Sample area (ha)	375	1873	633	1030	1210	759
Sampled groves	44	57	21	28	25	34
Technology	Percent of area equipped with technology					
Traditional (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
Micro-sprinkler	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] Aggregated data not available.

The period of interest for purposes of this study began in the fifties (although data for some technologies exist from the beginning of the century), when hand-moved sprinkers replaced the traditional furrow irrigation in some established groves and also became the irrigation technology introduced in newly established groves. The hand moved sprinklers

TABLE 2

Plantation and adoption periods for irrigation technologies in different regions in the sample

Region	Gaza	Negev	Lackish	Rehovot	Ra'anana	Hadera
Plantation period	1930–68	1954–74	1954–64	1932–79	1920–78	1901–67
	Observed adoption period					
	$t_0 - t_\tau$	$t_0 - t_\tau$	$t_0 - t_\tau$	$t_0 - t_\tau$	$t_0 - t_\tau$	$t_0 - t_\tau$
Furrow	1930–68			1932–57	1920–54	1901–61
Hand-moved		1954–64	1954–64	1950–63	1946–64	1946–67
Above-canopy				1965–68	1960–72	1949–77
Drag-line		1960–73	1962–72	1960–76	1962–75	1960–77
Solid-set	1977–78	1961–81	1970–80	1965–80	1970–76	1960–84
Micro-sprinklers	1975–83	1970–85	1975–81	1973–85	1970–83	1970–84
Drip		1967–86	1970–81	1972–82	1978–81	1976–85

t_0 = first year with observations on adoption.
t_τ = last year with observations on adoption.

system, consisting of aluminum pipes, was labor-tensive and allowed very little flexibility with regard to irrigation schedule.

Drag-line systems which were first introduced in the early sixties have been in use for the longest period of time, although this technology is labor-intensive and very difficult to control. The introduction of solid set sprinkelrs both above and under the canopy saved labor and contributed to better control of water application to individual trees. Both of these technologies however, are capital intensive and labor extensive in comparison to the traditional furrow irrigation. Other disadvantages associated with the solid set technologies involve operational difficulties, irrigation water uniformity, and salinity problems (in the case of above-canopy).

Micro-jet and micro-sprinker systems (hereafter referred to as micro-sprinklers) introduced in the seventies are capital intensive, but require only low water pressure, save labor, provide better irrigation water uniformity, and are easy to control. Drip irrigation systems demonstrate the same advantages as micro-sprinkers, and are also less capital intensive than micro-sprinklers.

For the purpose of estimating the effect of economic variables on diffusion, three variables were used. The first variable is the export price (P_{t-t}) for the *shamuti* variety of citrus ($ per 10 kg), on the assumption that *shamuti* prices represent other citrus variety prices. (*Shamuti* is also the main crop in the data base.) The information for constructing this variable was collected from data recorded in the Statistical Abstract of Israel (various years) with values represented in 1984 constant dollars. The second explanatory variable is water price (P^{W}_{t-t}), calculated in $\$/m^3$ ($1233.5\ m^3 = 1$ acre-foot) from the Statistical Abstract of Israel (various years) assuming the same price for all regions. This assumption is quite reasonable under conditions prevailing in Israel since water prices are dictated by a central authority which does not discriminate among regions. The third variable is the subsidy rate (S_{t-t}) on government loans for irrigation equipment (Israel Ministry of Agriculture, various years). These rates may differ by technologies, but it is assumed that no difference exists between regions. This assumption holds for the regions included in the data base, but not necessarily for other regions which may receive preferred subsidy rates.

For the purpose of estimating the diffusion logistic curves for solid set, micro-sprinklers, and drip, no distinction is made among regions and all 209 observations are grouped in one data set.

RESULTS

Data on the current shares of the different irrigation technologies in various regions are presented in Table 1. In 1987, more than 50% of the grove area (groves and growers may be used hereafter in the same context) was equipped with modern irrigation technologies. The diffusion processes of these technologies began in the ealry sixties to the early seventies depending on the region and the irrigation technology (Table 2). Hand-moved sprinklers were adopted in the fifties in five regions, but by 1987 this system was no longer in use (except for less than 1% of the area in Hadera). Above-canopy sprinklers were adopted in the three northern regions (Rehovot, Ra'anana, and Hadera), but are found today in only 2.3% and 7.9% of grove area in Ra'anana and Hadera regions, respectively. Drag-line sprinklers were adopted by growers in five regions but are used today on only 32% of the citrus groves in Negev, 40.5% in Lackish, 21.4% in Rehovot, 23.8% in Ra'anana, and 8.3% in Hadera.

For each irrigation technology with declining use over time, data are available on the number of groves currently practicing that technology (as of 1987), and annual number of adopters from as early as 1901 to 1987. The missing piece of information relates to the number of growers abandoning the technology each year. The procedure developed to estimate the technology cycle was applied to the data on furrow, hand-moved, above-canopy, drag-line, solid-set, and micro-sprinklers for each region separately. (The technology cycle can not be applied to technologies still in a diffusion process using the approach developed here.) Results for the technology cycle estimates are presented in Table 3. The estimated technology cycle for furrow irrigation is 26–30 years; the cycle for hand-moved sprinklers is 22–24 years, for above-canopy sprinklers it is 26–28 years; for drag-line sprinklers it is 17–20 years; for solid-set sprinklers it is 17 years (only in the Negev); and for micro-sprinklers the cycle is 15–17 years (only for Negev and Hadera Regions). In general, the Negev and Lackish regions exhibit shorter technology cycles for all irrigation technologies than the other

TABLE 3

Estimated irrigation technology cycles (years)

Tech.	Gaza	Negev	Lackish	Rehovot	Ra'anana	Hadera
Furrow	28	–	–	30	26	26
Hand	–	22	23	24	22	23
Above	–	–	–	26	27	28
Drag	–	18	18	20	19	17
Solid	–	17	*	*	*	*
Micro	*	15	*	*	*	17
Drip	–	*	*	*	*	*

Note: – Was not in use. * Still in the diffusion process.

regions. However, these differences were not found to be statistically significant.

The number of farmers using a particular irrigation technology being renounced, was calculated for each region using the technology cycle. Then quadratic logistic equations were estimated using a non-linear, iterative, least squares procedure (SAS, 1985). Since there is a tremendous volume of information, only results for Rehovot and Hadera regions are presented in Table 4. A curve depicting the estimated diffusion and abandonment of drag-line sprinklers in Hadera region is presented in Fig. 2. Results for all regions and technologies can be found in Dinar and Yaron (1988).

The coefficients presented in Table 4 (and additional coefficients that are not presented) were used to estimate the year when the diffusion process reached its ceiling for different technologies. Application of the procedure (equation 9) to the drag-line sprinkler equation (Table 4), indicates that the ceiling was reached 15–19 years after the beginning of the diffusion process (depending on the region). For technologies being renounced (but not yet abandoned), the coefficients in Table 4 also make it possible to estimate, the year when a technology will be fully abandoned.

TABLE 4

Estimated logistic quadratic diffusion and abandonment curves for technologies being abandoned, by regions [a]

	Irriation technology			
	Furrow	Hand-moved	Above canopy	Drag-line
Rehovot region				
R^2	0.865	0.800	0.565	0.957
b_1	0.403	0.168	0.995	0.132
	(0.054)	(0.025)	(0.284)	(0.016)
b_2	−25.15	−4.14	−2.77	−3.59
	(3.817)	(0.857)	(5.268)	(0.582)
b_3	482.09	40.92	61.29	46.64
	(66.263)	(7.057)	(21.998)	(4.926)
Hadera region				
R^2	0.908	0.836	0.764	0.926
b_1	0.430	0.237	0.819	0.444
	(0.031)	(0.032)	(0.262)	(0.049)
b_2	−36.91	−7.24	−25.10	−11.02
	(2.997)	(1.259)	(9.693)	(1.556)
b_3	916.86	76.91	333.62	103.91
	(70.943)	(11.924)	(86.623)	(11.923)

In parentheses are asymptotic standard deviations of the coefficients.

[a] Results are presented for only two regions. Additional results are available upon request.

For the drag-line sprinklers that were still in use on small portions of groves in the various regions, it is estimated (not presented) that this technology will disappear 30–35 years after initial adoption. Specifically, it is estimated that during the year 1990, drag-line systems will no longer be used in the Negev, lackish, and Hadera regions; and in 1995 they will also disappear from Rehovot and Ra'anana regions. Similar estimates exist for other technologies and are available upon request.

The three 'modern technologies' – solid-set sprinklers, micro-sprinklers and drip systems – are used in all regions (except for Gaza where drip was not used). Therefore, aggregated logistic diffusion curves were estimated for the sample data. A range of lag periods from 1 year to 5 years was used in the analysis (not presented), however, a lag of one year provided the most reasonable results. A one-year lag is therefore used here, assuming that a decision regarding the installation of a technology in year t depends upon conditions existing in year $t-1$. Some difficulties were encountered in estimating these logistic curves. In all cases the Durbin-Watson (D.W.) statistic is in the intermediate range, indicating inconclusive results with regard to positive serial correlation. Draper and Smith (1981) suggest such cases be treated as if a serial correlation had been found. Because of these difficulties, the coefficients are not presented. In order to correct for the possible presence of first order serial correlation, the Hildreth–Lu procedure (Pyndick and Rubinfeld, 1981) was applied. The corrected logistic expression is now:

$$\boldsymbol{N}_t = d_1'/\left[1 + \exp\left(-d_2' - \psi_0 t - \psi_3 t\boldsymbol{P}_{t-1} - \psi_4 t\boldsymbol{P}_{t-1}^{W} - \psi_5 t\boldsymbol{S}_{t-1}\right)\right] \quad (12)$$

where

$$\boldsymbol{N}_t = N_t - \gamma N_{t-1}$$

$$\boldsymbol{P}_{t-1} = P_{t-1} - \gamma P_{t-2}$$

$$\boldsymbol{P}_{t-1}^{\mathrm{W}} = P_{t-1}^{\mathrm{W}} - \gamma P_{t-2}^{\mathrm{W}}$$

and

$$\boldsymbol{S}_{t-1} = S_{t-1} - \gamma S_{t-2}$$

and γ is a scalar of grid values ($0 \leqslant \gamma \leqslant 1$).

Equation (12) was estimated for a range of γ values using the same procedure as equation (10). The chosen value for γ is that given by the smallest sum of squared residual for the regression runs. The chosen values of γ are presented in Table 5 for each technology; an autoregressive transformation was performed and the results of the regression runs are also presented. Values for the D.W. statistic are now higher than in the

TABLE 5

Logistic curves for the diffusion of several modern irrigation technologies (corrected for serial correlation)

Dependant variable:	Share of groves using the technology		
	Irrigation technology		
	Solid-set	Micro-sprinkler	Drip
γ	0.2	0.3	0.4
Asymptotic R^2	0.997	0.997	0.995
d_1'	0.358	0.561	0.234
	(0.003)	(0.006)	(0.003)
d_2'	−4.93	−8.26	−6.34
	(0.178)	(0.279)	(0.246)
ψ_0	0.352	0.419	0.308
	(0.014)	(0.014)	(0.013)
ψ_3 (yield price)	0.00044	0.00300	0.00310
	(0.0012)	(0.0008)	(0.0010)
ψ_4 (water)	0.00052	0.00481	0.00550
	(0.0018)	(0.0013)	(0.0021)
ψ_5 (subsidy)	0.01	0.03	0.05
	(0.0063)	(0.0072)	(0.0099)
D.W.	2.01	1.95	1.98
Actual share of adopters at 1987	0.35	0.51	0.22

In parenthesis are asymptotic standard deviations.

original regression, indicating that no serial correlation exists in the transformed estimated residual.

In all cases the estimated ceiling (d_1') is higher than the actual share of adopters in 1987, indicating that the diffusion process will reach its ceiling after that year. All coefficients affecting the diffusion process behave as reported in the literature: an increase in *shamuti* export price, in water price, and in subsidy rate for modern irrigation equipment, will increase the share of the modern technologies used in citrus groves. These findings are in agreement also with results provided by Caswell and Zilberman, 1985). The speed at which the ceiling will be reached can also be influenced by those variables. For example (not presented in the tables), if export prices remain at 1987 level while holding all other variables constant, ceiling will be reached in the years 1999, 2000, and 2001 for solid-set, micro-sprinklers, and drip, respectively. If export prices increase by 10% ceiling will be reached one year earlier than in the previous case for all technologies. A decrease of the same rate in export price will result in a one-year delay in approaching the ceiling for all technologies.

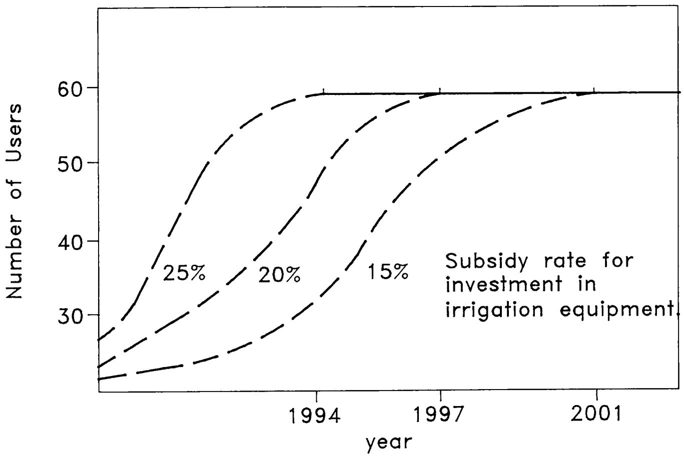

Fig. 3. Effect of subsidy for irrigation equipment on the diffusion of drip (national data).

There are some tradeoffs between greater use of modern technologies, or shorter adoption periods, and social cost. For example, in case of externalities in the production process related to irrigation, a regional authority might be interested in transition to more efficient irrigation technologies. This change is associated with additional investment that might be subsidized by society through tax dollars, and should therefore be evaluated in this regard. The effect of changes in subsidy rates for irrigation equipment on diffusion of drip is demonstrated in Fig. 3. A subsidy

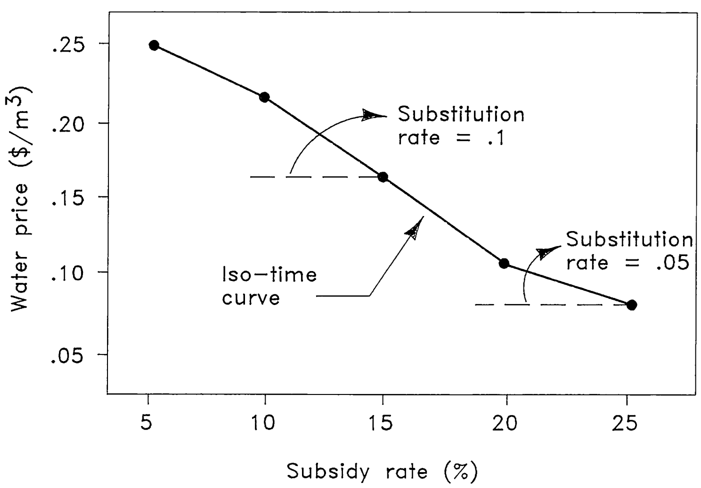

Fig. 4. Substitution between water price and subsidy for irrigation equipment in order to reach the ceiling of the diffusion process for drip at year 2000 (national data).

rate for irrigation equipment of 20% would result in reaching the ceiling four years earlier (1997 instead of 2001) than with a subsidy rate of 15%, where as with a subsidy rate of 25%, the diffusion reaches ceiling in 1994. The time gained by the increased subsidy can be weighted against possible losses resulting from continued use of the existing irrigation technology.

Another demonstration of the usefulness of the results is presented in Fig. 4. Here two policy variables are substituted in order to achieve the ceiling of the diffusion process for drip irrigation at year 2000: water price and subsidy rate, both of which can be controlled by the government and used for policy purposes. By drawing a substitution curve between these two policy variables (using the estimated equation for drip irrigation in Table 5), it was found that the substitution rate is larger in cases where water prices are high (substitution rate of 0.1) than in cases of low water prices (substitution rate of 0.05). These findings can, therefore, serve the policy maker to optimize the combination between these two variables.

CONCLUSIONS

In this study adoption and abandoment processes of irrigation technologies in citrus groves were estimated and depicted. Data from Israel and Gaza were used to: (1) estimate technology cycles for different irrigation technologies, (2) estimate, using the technology cycle, the process of diffusion-abandonment of technologies already in the process of renouncement, and (3) confirm hypotheses established in previous theoretical and empirical studies with regard to the effects of input and output prices on the diffusion processes of irrigation technologies still in the diffusion phase.

It was found that the technology cycle length for a given technology is dependent only on the technology and not on physical conditions prevailing in different regions (e.g., weather, soil types etc.). For technologies being abandoned, the technology cycle was used to estimate the year of discontinuance. These findings can serve policy makers of developing agricultural regions, as well as manufacturers of irrigation equipment who are interested in predicting years of use for a given technology.

In many cases, policy makers must consider the effects of possible policies on the behavior of growers in order to achieve changes in resources use. For example, in the United States, the new 1990 Farm Bill considers policies to improve water conservation and reduce pollution problems. In Asia, as irrigation water becomes the binding constraint for rice production, improvements in irrigation efficiencies will need to be found. Studies suggest, among other means, that farmers should improve their irrigation performances by transition to modern irrigation practices. The current study, although based on data from one region, provides insights that can be used elsewhere. Effects of input and output prices on diffusion of modern irrigation technologies were estimated and used to demonstrate the effectiveness of possible combinations of policy variable levels on achieving a range of technology diffusion rates. These variables were found to be very effective in determining rate and ceiling of the diffusion process.

ACKNOWLEDGEMENT

This study was supported in part by the U.S. Agency for International Development to the Hebrew University of Jerusalem as a part of a Tri-national Egypt–Israel–U.S.A. 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. Helpful comments to this version were provided by the Editor-in-Chief and an anonymous reviewer.

REFERENCES

Bishop, R. and Coughenour, C.M., 1964. Discontinuance of farms innovations. Bull. AE 361, Department of Agricultural Economics and Rural Sociology, Ohio State University, Columbus, OH.

Cameron, H.M. and Metcalfe, J.S., 1987. On the economics of technological substitution. Technol. Forecast. Social Change, 32: 147–162.

Casterline, G., Dinar, A. and Zilberman, D., 1989. The adoption of modern irrigation technologies in the United States. In: A. Schmitz (Editor), Free Trade and Agricultural Diversification: Canada and the United States. Westview, Boulder, CO, pp. 222–248.

Caswell, M. and Zilberman, D., 1985. The choices of irrigation technologies in California. Am. J. Agric. Econ., 67: 224–234.

Coughenour, C.M., 1961. The practice-use tree and the adoption, drop-out, and non-adoption of recommended farm practices: a progress report. Paper presented at Rural Sociological Society Meeting, Ames, IA.

Deutschmann, P.J. and Hevens, A.E., 1965. Discontinuances: a relatively uninvestigated aspect of diffusion. Department of Rural Sociology, University of Wisconsin, Madison, WI.

Dinar, A. and Letey, J., 1989. Economic analysis of charges and subsidies to reduce agricultural drainage pollution. In: J.B. Summers (Editor), Proc. 2nd Pan-American Regional Conf. Toxic Substances in Agricultural Water Supply and Drainage – An International Environmental Perspective, Ottawa, Ont., Canada – U.S. Committee on Irrigation and Drainage, Denver, CO, 8–9 June, pp. 53–70.

Dinar, A. and Yaron, D., 1988. 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. A Tri-national Project Egypt–Israel–U.S.A., 71 pp.

Dinar, A. and Zilberman, D., 1991. Effects of input quality and environmental conditions on selection of irrigation technologies. In: A. Dinar and D. Zilberman (Editors), The

Economics and Management of Water and Drainage in Agriculture. Kluwer, Boston, MA, pp. 229–250.
Draper, N.R. and Smith, H., 1981. Applied Regression Analysis (2nd Edition). Wiley, New York.
Easingwood, C.J., 1988. Product life cycle patternsfor new industrial products, R&D Manage., 18: 23–32.
Feder, G., Just, R.E. and Zilberman, D., 1985. Adoption of agricultural innovations in developing countries, a survey. Econ. Dev. Cult. Change, 33: 255–298.
Feder, G., Onchan, T., Chalamwong, Y. and Holgladarom, C., 1988. Land Policies and Farm Productivity in Thailand. Johns Hopkins University Press for Wold Bank.
Fishelson, G. and Rymon, D., 1989. Adoption of agricultural innovation: the case of drip irrigation of cotton in Israel. Technol. Forecast. Social Change, 35: 375–382.
Fisher, J.C. and Pry, R.H., 1971. A simple substitution model for technological change. Technol. Forecast. Social Change, 2: 75–84.
Grilliches, Z., 1960. Hybrid corn and the economics of innovations. Science, 132: 275–280.
Guttman, J.M. and Haruvi, N., 1986. Cooperating and part-time farming in the Israeli moshv. Am. J. Agric. Econ., 68: 77–87.
Hayami, Y. and Ruttan, V.W., 1971. Agricultural Development: An international Perspective. Johns Hopkins University Press, Baltimore, MD.
Israel Ministry of Agriculutre, various years. Bureau of the Water, Department for irrigation efficiency, Price Lists and Loan Terms. Tel Aviv, Israel (in Hewbrew).
Jansen, H.G.P., Walker, T.S. and Barker, R., 1990. Adoption ceilings and modern coarse cereal cultivars in India. Am. J. Agric. Econ., 72: 653–663.
Jarvis, L.S., 1981. Predicting the diffusion of improved pasture in Uruguay. Am. J. Agric. Econ., 63: 496–502.
Kislev, Y. and Shchori-Bachrach, N., 1973. The process of an innovation cycle. Am. J. Agric. Econ., 55: 28–37.
Kulshreshtha, S.N., 1989. Irrigation and prairie agricultural development. In: A. Schmitz (Editor), Free Trade and Agricultural Diversification: Canada and the United States. Westview, Boulder, CO, pp. 222–248.
Mansfield, E., 1963. Intrafirm rates of diffusion of an innovation. Rev. Econ. Stat., 45: 348–359.
Pindyck, R.S. and Rubinfeld, D.L., 1981. Econometric Models and Economic Forecasts (2nd Edition), McGraw-Hill, New York.
Rifas, B.E., 1957. Replacement models. In: C.W. Churchman, R.L. Ackroff and E.L. Arnoff (Editors), Introduction to Operations Research, Wiley, New York.
Rogers, E.M., 1983. Diffusion of Innovations (3rd Edition). Free Press, New York. SAS, 1985. SAS User's Guide: Version 5 Edition. SAS Institute Inc., Cary, NC.
Statistical Abstract of Israel, various years. Central Bureau of Statistics, Jerusalem.
Thirtle, G.C. and Ruttan, V.W., 1987. The Role of Demand and Supply in the Generation and Diffusion of Technical Change. A volume of the Economics and Technological Change section, edited by F.M. Scherer, Harwood Academic Publications, New York.