# The Economics of Water-Conserving Technology Adoption in Tunisia: An Empirical Estimation of Farmer Technology Choice*

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## Introduction

Economic theory tells us that increases in the relative prices of natural resources should cause farmers to switch to techniques that use fewer farming resources. The adoption of resource-conserving technology is one possible response that can lead toward a more environmentally sustainable outcome. Do farmers respond to changes in natural resource prices and quality by adopting available resource-conserving technology? This article investigates a case study of decisions made by Tunisian farmers as to whether or not they should invest in water-conserving drip-irrigation technology as a function of natural resource prices and quality, along with farm and farmer characteristics. In contrast to many studies of technology adoption, this work uses both the standard revealed preference analysis of who adopts and a direct elicitation of the reasons for adoption or nonadoption by farmers. By reviving an ancient methodology—the direct question—to elicit real preferences from farmers, the research goes beyond the restrictive assumptions of the commonly used random utility models. The combination of these techniques allows triangulation on the causes of technology adoption and helps insure that the results are more than a statistical artifact.

The survival and continued growth of the economy of Tunisia as well as that of other North African countries depends vitally on the sustainable use of water resources. Access to sufficient quantities of water remains a major limiting factor in Tunisian agriculture.[1] Government policies of the last 3 decades have promoted irrigated cropping patterns at the expense of dryland farming. The consequence has been an increase in water use in the agricultural sector from both renewable and nonrenewable sources. At the same time, economic expansion in the other major sectors of the Tunisian economy (industry and tourism) has increased competing water demand outside the ag-

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ricultural sector. The World Bank estimates that all of Tunisia's water resources are fully developed, causing competing demands for scarce supplies.[2] The adoption of drip-irrigation technology by farmers can conserve water in agriculture, thereby reversing the current unsustainable practices and leaving water available for the expansion of other sectors of the Tunisian economy.

The case study region of Cap Bon, which produces many of the country's export crops, has some of Tunisia's most productive irrigated lands. Among all regions of Tunisia, Cap Bon has the largest percentage of its population engaged in agriculture.[3] Even as irrigated agriculture has succeeded, water tables in the region have declined and become more salinated, thus threatening Cap Bon's agricultural potential. Safeguarding the agricultural production of Cap Bon through better water management has been one of the major policy objectives of recent agricultural development plans.[4] At the farm level, improving the current water management system implies some combination of farmer investment in water-conserving technology and a change in cropping patterns.

This work starts by developing a set of testable hypotheses governing the adoption of new technologies. I then estimate an econometric model to test these hypotheses using the revealed choices of farmers. These estimations describe farmer preferences as a function of farmer characteristics. As a check on the validity of these revealed-preference regressions, the next section asks farmers directly why they adopted or did not adopt drip-irrigation technology. The direct elicitation of preferences circumvents the potential danger of directing policies toward farmer characteristics rather than preferences. The conclusions explore how the results change our current understanding of the relationship between technology adoption and sustainability.

## A Theory of Individual Adoption Behavior

The diffusion process of how and why farmers adopt new technologies has elicited a large literature within the economics profession.[5] Much of the interest has focused on the causes of slow diffusion rates of profitable and socially beneficial technologies. The literature on the adoption of new agricultural technologies suggests several reasons for the slow diffusion of potentially profitable innovations. Each reason presents its own implications for which types of policies could best speed the diffusion of new technologies. Assuming that a new technology is more profitable than the old technology, the literature suggests the following four hypotheses for how and why new agricultural technologies spread throughout an area.

### *Hypothesis 1: Resource Scarcity*

Increasing scarcity of natural-resource endowments leads to higher shadow prices for the resource, causing farmers to switch to a resource-conserving technology. The resource scarcity hypothesis suggests that new technologies will diffuse appropriately at their own pace depending on the relative prices of resources in the area.[6] Early adopters of a new technology will be those with the most severe resource constraints, while those with abundant or inexpensive resource stocks will adopt later, if at all.

Appropriate policies to speed an adequate diffusion of technology that emanate from this theory include reducing market imperfections in the pricing of natural resources, reforming output price markets, and making sure farmers pay the “true” resource cost of their inputs. These policies form what is commonly found in “economic liberalization” packages under structural adjustment programs. In testing whether resource scarcity drives the diffusion of agricultural technology, one indirectly tests the appropriateness of a liberalization policy as a method for leading to environmentally sustainable production. A liberalization policy will, in theory, appropriately price resources to farmers. The question is whether they will in fact react to those price vectors by adopting a new technology.

### *Hypothesis 2: Capital Constraint*

Capital scarcity, caused by credit constraints or a lack of collateral, implies that farmers cannot undertake intertemporal consumption smoothing and make long-term investments. The capital constraint hypothesis suggests that new technologies will diffuse fastest among those who have the best access to capital to pay for the new technology.[7] Thus, farmers with the best access to capital will be the first to adopt while their capital-poor brethren may not adopt the new technology. Appropriate policies to speed technology adoption emanating from the capital constraint hypothesis include improving access to farm credit, reducing up-front capital costs of a technology, and providing investment credits to farmers for the new technology.

### *Hypothesis 3: Learning Cost*

A slow diffusion of knowledge of the technology implies that farmers do not know the benefits of a new technology and are therefore unwilling to risk adopting an unknown technology. The learning-cost hypothesis suggests that technologies will diffuse fastest in areas where information about the technology is most readily available and most easily evaluated by potential adopters.[8] Thus, farmers in areas with high exposure to extension services, with better levels of education, and greater degrees of adoption by neighbors will likely be earlier adopters of new technologies. Related to this is the degree of adaptation of the technology to the local conditions that farmers face. Testing this adaptation often involves a period of experimentation by farmers with the new technology or a period of observation as neighbors adopt the technology. In this way, the information cost associated with a given technology is subject to farmer management. Keys to the farmer’s ability to manage information costs may be farmer experience, education, or access to other farmers who have these attributes. This implies that appropriate policies to speed technology adoption will include increased extension work promoting the benefits of a new technology, use of demonstration plots in proximity to farmers, and increasing the farmers’ levels of education.

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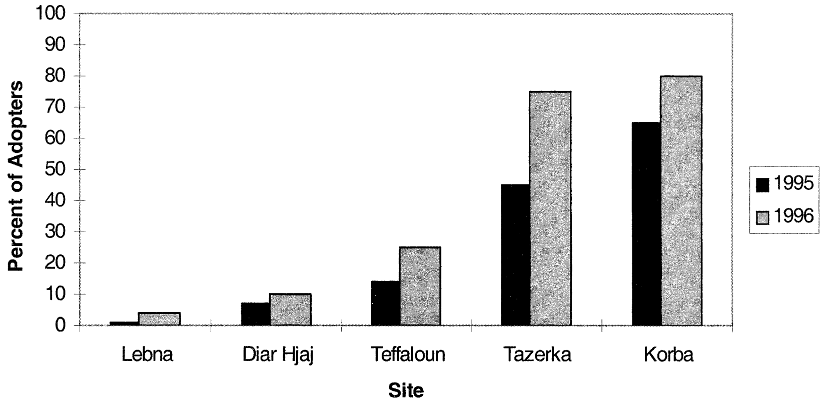

FIG. 1.—Diffusion of drip irrigation

*Hypothesis 4: Risk Aversion*

Risk aversion implies that farmers will not invest in unknown new technologies that potentially create a greater variance in output. The risk-aversion hypothesis has two facets: first, farmers are risk averse to an unknown technology; second, farmers are risk averse to a technology that increases the variance of their net income through a higher output variance.[9] Since drip q2 irrigation is a risk-reducing technology, under downside risk aversion, poor farmers will benefit most from the technology. However, risk considerations may be outweighed by capital constraints, since poor farmers who have the greatest need for risk reduction often will be those who are most capital constrained. For a risk-reducing technology, one would expect to see among early adopters of a new technology those who have the greatest risk exposure and those who can be most certain that the technology will work on their fields. Policy implications of the risk-aversion hypothesis for a risk-reducing technology combine those of the information and capital-constraint hypotheses and include improving the spread of information about the technology and reducing the risk cost of the technology.

## Geography of Adoption

The place to start this empirical investigation is with the geography of adoption. Can pure geographic proximity explain technology adoption rates? The survey sites represented a range of different stages of adoption even though the adoption process was still in its infancy. Figure 1 presents the percentage of adopters of drip irrigation for the different survey sites using the adoption rates in 1995 and 1996. The 1996 data are computed as 1995 adopters plus those nonadopters who said they intended to adopt the next year. The towns are lined up by adoption rate and show evidence of an “S” curve of adoption. Using the language of Everett Roger’s work, adoption seems to have taken off in Korba and Tazerka, while it seems to be at the verge of doing so in Teffaloune.[10] Diar Hjaj and Lebna are lagging behind.

This represents a strong geographic pattern to adoption. Drip irrigation was first demonstrated by extension agents in Korba, the place of highest adoption rates. The next highest rate of adoption is the town closest to Korba, which is Tazerka. The lowest rate of adoption is in Lebna, which is the place farthest from Korba. The town of Diar Hjaj is the one exception to this geographic pattern: it is as near to Korba as Tazerka is but has a very low rate of adoption. The geographic patterns do suggest that information about the technology may be a strong determinant of adoption, however, geography is also strongly correlated with natural resource problems. Thus, while there seems to be a strong geographic flow to the adoption of drip technology, geography cannot explain all of the variation in adoption patterns. I now turn to the estimation of revealed preferences of farmers for drip-irrigation technology.

## The Econometric Inference Problem

While the four hypotheses of technology adoption present differing causes for technology adoption, from an econometric point of view, they pose some identification problems. In many cases, farmers may not adopt a technology for a variety of reasons. The econometric inference problem is to identify which of the operative constraints predominates in a farmer's decision to adopt a technology. In this method, I use data on the characteristics of individual farmers and their respective adoption decisions to reveal their preferences as a function of their characteristics. In so doing, I assume that rational choice behavior governs farmers' decisions. A farmer takes a given set of alternatives and rationally chooses the preferred one. In this way his behavior reveals his preferences, which can then be described as a function of his observable characteristics.[11]

In this framework, technology adopters will be those with a positive net willingness to pay for the technology. These are the farmers who have a reservation price, $P^*(A, \mathbf{z}, \eta)$, for the technology that is greater than or equal to the actual market price, $P$. The reservation price is the amount that an individual would be willing to pay for the technology given his asset position, $A$; other inputs he uses, $\mathbf{z}$; and the parameters of his preference function, $\eta$. The market price is a parametrically given price of the technology, which is the same for all individuals.[12]

For a given individual, the dependent variable $Y$ is defined as an index variable for whether or not individuals adopt the new technology. It takes on the values of zero and one as follows:

$$Y = 1 \quad \text{if } P^*(A, \mathbf{z}, \eta) - P > 0, \tag{1}$$

$$Y = 0 \quad \text{if } P^*(A, \mathbf{z}, \eta) - P \leq 0, \tag{2}$$

where $A$ is the asset position of the farmer, $\mathbf{z}$ is the vector of nontechnology inputs, $\eta$ is the preference parameter, the function $P^*(A, \mathbf{z}, \eta)$ represents the shadow price for an individual of adopting the technology, and $P$ is the actual market price of the technology.

The econometric inference problem then becomes a question of parameterizing the equation that defines the net benefits of the technology to farmers. The standard model of preference choice in the literature is the random utility model.[13] As a researcher, one is unable to observe the preference parameters of the utility function but, instead, to assume that they are known to decision makers. Let these parameters be an unobserved variable $\varepsilon$ so that actual utilities of an individual can be written as $U_i = P_i^*(A, \mathbf{z}, \eta) - P = \boldsymbol{\beta}'\mathbf{X} + \varepsilon$, where $\mathbf{X}$ is a set of characteristics of the decision maker observable to the econometrician, and $\boldsymbol{\beta}$ is a parameter vector. Here $\boldsymbol{\beta}'\mathbf{X}$ becomes an index function that allows us to estimate the probability of adoption: that $Y = 1$ in the following fashion,

$$\text{Prob}[P^*(A, \mathbf{z}, \eta) - P > 0] = \text{Prob}(\boldsymbol{\beta}'\mathbf{X} + \varepsilon > 0). \tag{3}$$

Assuming that the disturbance term is normally distributed, this becomes a standard probit model. By symmetry of the normal distribution, one gets:

$$\text{Prob}(P^* - P > 0) = \text{Prob}(\varepsilon < \boldsymbol{\beta}'\mathbf{X}) = F(\boldsymbol{\beta}'\mathbf{X}), \tag{4}$$

where $F(\cdot)$ is the cumulative density function of the normal distribution. This then is estimated using maximum likelihood estimation, in which the likelihood function is as follows:

$$\ln L = \sum_{y_i=0} \ln(1 - \Phi_i) + \sum_{y_i=1} \ln(\Phi_i), \tag{5}$$

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where $\Phi_i = F(\boldsymbol{\beta}'\mathbf{x}_i)$. One then obtains the asymptotic covariance matrix for the estimator from the inverse of the Hessian matrix evaluated at the estimated parameters.

## The Data Implementation

In parameterizing the net worth of the new technology, one can start with the farmer's natural resource situation. Appropriate variables will measure both the price and quality of the farmer's water resources. As a measure of the cost of water, the variable "Water_94" measures the per hectare amount farmers paid in the previous year for pumping water on their land.[14] It also provides a proxy measure for the water quantity problems that farmers face, since lower quantities of water in the aquifer will imply greater per hectare pumping costs. As a measure of water quality problems, "Salinity" measures the salt content of the water in grams per liter. All of the surveyed farms were within 10 miles of the sea and suffered from relatively high levels of salinity.[15] Since drip irrigation reduces water usage and reduces the effects of salinity on plants, farmers with higher water costs and higher salinity are predicted to be earlier adopters.

The farmer who wants to adopt a new technology must have access to sufficient capital in order to pay for the technology either with his own funds

TABLE 1

Descriptive Statistics

| Variable | Variable Description | Mean | Standard Deviation | Minimum | Maximum |
|---|---|---|---|---|---|
| Water_94 | Amount spent on water in the previous year, 1994 ($ per hectare) | 274.6 | 212.5 | 19.7 | 1,166.7 |
| Salinity | Degree of salinity of irrigation water in grams per liter | 2.16 | .814 | 1.0 | 6.0 |
| Expenditure | Monthly household expenditure per person ($) | 39.5 | 26.04 | 5 | 200 |
| Debt | Whether a household was able to borrow money (0–1) | .77 | .43 | 1 | 0 |
| Saw Drip | Number of years since farmer first saw drip irrigation | 1.79 | 2.91 | 0 | 28 |
| Education | Level of farm operator education* | 2.26 | 1.15 | 1 | 5 |
| Farm Size | Operated farm size in hectares | 5.49 | 15.85 | .4 | 180 |
| Simpson | Index measure of crop diversification | 2.87 | 1.32 | 1 | 7.2 |
| Percent Owned Land | Percentage of operated land owned by the operator | 44 | 45 | 0 | 100 |
| Percent Strawb | Percentage of land in strawberries | 12 | 23 | 0 | 100 |

* The education variable is coded as follows: 1 = no formal education, 2 = Koranic education, 3 = grade school, 4 = high school, 5 = college. Note that typically Koranic education was a very basic grade school education that taught reading and writing in Arabic script.

or through access to credit. The two variables used here are household expenditure and a variable capturing whether or not the farmer was able to borrow money. Richer farmers and those with better access to credit can be expected to be earlier adopters of drip irrigation. In the process of deciding whether or not to adopt drip-irrigation technology, farmers must first be aware of its existence and understand how it works. One can measure the possibilities farmers have for learning about drip irrigation through their educational levels and how long they have known about the technology. The information variables (table 1) used are “Saw Drip,” which measures how long the farmer has known about the technology, and “Education,” which measures the farmer’s educational level.

Two variables are included to measure risk. “Farm Size” is the operated size of farms, including land rented in or sharecropped. The “Simpson Index” is a variable created to measure diversification among crops as a proxy for farmer risk exposure.[16] Larger farms and more diversified farms will likely have better methods of spreading risk and thus be less likely to adopt the technology for risk reasons. Since tenure insecurity may reduce the incentives to adopt new technologies, "Percent Owned Land" is included as a variable that measures tenure insecurity. It takes the value of 100 for farms that are entirely owner operated and a value between zero and 100 otherwise. A percentage of owner operation is used here, since many of the operated farms had multiple tenure arrangements on their land. The nonowner-operated land was either rented, sharecropped, or some combination of the two. For the purposes of this analysis, rental and sharecropping are considered equally insecure in terms of their effect on technology adoption. Finally, KRTZDH is a regional dummy variable for farms in Korba, Tazerka, and Diar Hjaj. They are within 10 kilometers of the point where the technology was first introduced. As well as controlling for some regional differences, it also partially measures the spatial diffusion of a technology. Farmers in this 10-kilometer radius have received the highest degree of extension work on drip irrigation and were most likely to have a neighbor, relative, or friend who has already adopted the technology.

The vast majority of the adopters of drip irrigation were strawberry farmers. Not all strawberry producers who adopted drip irrigation used it on their strawberry fields; nonetheless, it presents a quandary for this analysis. Strawberry producers who are in the area where the technology was first introduced tend to be wealthier and more able to afford a new technology. If one uses strawberry production as an explanatory variable, it will likely explain a lot of the adoption behavior. However, we may actually be masking the underlying variables that cause adoption. We may attribute adoption behavior to crop choice rather than the underlying variables that are correlated with that crop choice. This suggests a restricted and unrestricted version of the estimation. I therefore estimate two separate models. The first model ignores the type of crops a farmer grows, while the second uses the percentage of land devoted to strawberries as an explanatory variable.

### Probit Estimates

Table 2 presents results from the probit estimation of drip-irrigation adoption, along with the asymptotic standard errors. The estimations predict at a high level, with the probit equations correctly predicting over 80% of the adoption decisions of Cap Bon farmers. The models produce signs and magnitudes mostly consistent with the theory presented above.

Comparing the results from model 1 and model 2 confirms the hypothesis that growing strawberries is highly correlated with adoption of drip irrigation. Our measure of the degree to which strawberries are an important crop subsumes a lot of the variation in the sample. Despite that, a number of variables still retain some explanatory power, particularly the information and credit variables. This suggests that even among similar farmers growing similar crops, information and capital access will factor into adoption decisions. The large and significant estimated coefficient on strawberry production does not,

TABLE 2

Estimation of Farmer Technology Adoption Decisions

| Variable | Model 1 | Model 2 |
|---|---|---|
| Water_94 | .00016 | .00018 |
|  | (.00088)* | (.001) |
| Salinity | −.069 | .084 |
|  | (.224) | (.239) |
| Expenditure | .0004 | .0025 |
|  | (.0065) | (.0071) |
| Debt | 1.05 | .969 |
|  | (.4728)** | (.557)* |
| Saw Drip | .141 | .153 |
|  | (.0746)* | (.080)* |
| Education | .156 | .127 |
|  | (.137) | (.144) |
| Farm Size | −.087 | −.027 |
|  | (.083) | (.081) |
| Simpson | .0538 | .221 |
|  | (.144) | (.161) |
| Percent Owned Land | −.0036 | −.002 |
|  | (.0039) | (.004) |
| Percent Strawb |  | .035 |
|  |  | (.011)** |
| KRTZDH | 1.12 | .698 |
|  | (.435)** | (.482) |
| Constant | −3.18 | −4.14 |
|  | (.961)** | (1.180)** |
| Log likelihood | −44.49 | −37.89 |
| Percent predicted correctly | 80 | 86 |
| Mcfadden $R^2$ | .36 | .46 |

Note.—Standard errors are in parentheses below the coefficient estimates. $N = 133$. KRTZDH is a regional dummy variable for farms in Korba, Tazerka, and Diar Hjaj.

* Significant at the 10% level.

** Significant at the 5% level.

however, suggest that we should turn all farmers into strawberry growers to induce adoption of drip irrigation.

Among the natural resource variables, “Water_94” has an estimated parameter significantly different from zero but only when one ignores the strawberry acreage. The salinity measure is insignificant and in one case has the opposite than predicted sign. The natural resource variables suggest that higher water costs dominate water quality in terms of their effects on technology adoption decisions. A simple correlation run between adoption decisions and whether farmers, when asked, stated they had water problems yielded very little correlation (0.06). This, along with the regression results, suggests that the difference between adopters and nonadopters is only partially dependent on the quality and cost of resource stocks they manage.

The key significant variables in both models point to the farmers with the highest probability of adopting as those without information and credit constraints. The estimated coefficients for “Saw Drip” and “Debt” and the regional dummy variable in model 1 have the anticipated signs and are significantly different than zero at a 10% or better confidence interval. Farmers who have greater knowledge of the technology and have access to sufficient capital tended to be earlier adopters of drip irrigation. These represent a combination of market and government imperfections that are subject to policy interventions, such as improving extension services and removing interest rate ceilings. The insignificant coefficients on “Farm Size” and “Simpson Index,” used as a measure of on-farm diversification, provide little evidence to support the idea that farmers would adopt the technology to reduce risk.

The measures of the information diffusion hypothesis lend credence to the possibility that farmers are constrained by the availability and processing of information on the new technology. The variable measuring farmer proximity to the technology’s first introduction, “KRTZDH,” shows a significantly positive effect on adoption. While this may be capturing many other regional differences, the evidence from “Saw Drip” lends support to the idea that the earlier a farmer has access to information the more likely he is to adopt the technology.

### Actual Preferences

The previous section assumed that preference parameters were some unobserved random variable, normally distributed with mean zero. Using observations of farmer behavior and information about their characteristics, I have interpreted a preference set and a motivation to their actions. This imposes an interpretation of farmer motivation from the correlates of behavior and farmer characteristics that may be ascribing too much motivation to characteristics rather than actual preferences of individuals. Only if characteristics (e.g., wealth, education level) entirely determine—or are highly correlated with—preferences does one not have this problem of misidentification of the types of individuals who might adopt. In many cases, observations of behavior may misidentify the cause by ascribing cause to characteristics rather than to actual preferences.[17] For example, the statistically insignificant coefficient estimates on natural resource quality were interpreted as indicating that it is not a leading motivation for farmers to adopt drip irrigation. One cannot infer from this information, however, that farmers are unconcerned with an increased salinization of their irrigation water. The danger from a policy standpoint is that one directs policies toward characteristics rather than preferences.

Instead of assuming that preferences are unobservable to the econometrician, though known by the individuals, one might instead ask individuals for their actual preferences. I therefore turn to a direct elicitation of the determinants of farmer technology adoption decisions: asking farmers why they did or did not adopt a technology. Eliciting direct statements of preferences, while common in sociological and psychological studies, remains rare in

TABLE 3

Reasons for Adopting Drip Irrigation (%)

| Why Did You Adopt Drip Irrigation? | Reduces Water Requirements (1) | Increases Yields (2) | Reduces Work Requirements (3) | Reduces Inputs (4) | Other* (5) |
|---|---|---|---|---|---|
| Reason 1 ($N = 31$) | 45 | 35 | 10 | 0 | 10 |
| Reason 2 ($N = 20$) | 30 | 5 | 35 | 20 | 10 |

* Other reasons for adopting drip irrigation as stated by farmers include reduction in the risk of plant diseases, it is cleaner than the old technology, and "the neighbors use it."

economics. Economists in general prefer the revealed preference methods because they are thought to be "internally consistent" and more independent of measurement problems.[18] The measurement problems in direct preference revelation come from respondents being unable to adequately describe their choice process, answering dependent on the wording of a question, and the subjective nature of preferences themselves as data.

### Actual Preference Results

In order to implement direct preference revelation, each technology adopter was asked for his or her primary reasons for adopting drip irrigation.[19] The results of that questioning appear in table 3. The results suggest that adopters of the technology were receiving benefits from drip irrigation similar to those experienced on research stations. They adopted drip irrigation primarily for the technology's water-conserving qualities, with a majority claiming this as one of the two main reasons for adopting. The potential yield increases from drip irrigation were important for a large number of farmers but were overshadowed by input (water, labor, and chemical) conservation properties. This evidence would lend credence to the idea that resource constraints predominate in a farmer's decisions to adopt the new technology. It suggests that those who adopt the technology do so at least partially to conserve their input usage.

If adopters do so to conserve their resources, why do nonadopters refrain from investing in this new technology? Table 4 presents the results of asking the nonadopters of the technology about their reasons for not adopting drip irrigation. The first three most frequent answers are broadly suggestive of capital constraints, information constraints, and problems with insecure land tenure arrangements as the primary reasons for not adopting the new technology. A farmer who did not need the lower input usage of drip irrigation would be expected to choose reason number 5. Since so few chose this, it suggests that the resource conservation needs of the adopters and nonadopters are similar. This implies that credit, information, and tenure constraints impinge on farmer adoption decisions so that they cannot make resource-conserving investments. Equally suggestive of the constraints facing farmers is

TABLE 4

Reasons for Not Adopting Drip Irrigation (%)

| | No Capital Available or Too Expensive (1) | Do Not Know How to Use It* (2) | Insecure Tenancy (3) | Have Not Had the Time (4) | Do Not Need It for My Farm (5) | It Is Too Much Work (6) |
|---|---|---|---|---|---|---|
| Why have you not adopted drip irrigation? ($N = 103$) | 37 | 26 | 18 | 10 | 6 | 3 |

* Includes those who said "drip irrigation technology does not work."

that among those who have not adopted drip irrigation, 64% said they thought they would benefit from using it.

### Comparing Revealed and Direct Preferences

Direct revelation presents some methodological advantages in that it does not presume that the researcher knows a person's mind better than he does. Combined with the revealed preference analysis, the direct revelation validates credit constraints and information as primary causes of nonadoption. Direct revelation also showed tenure insecurity as a reason for not adopting, which perhaps points to poor measurement of this variable in the current data set. There is something about the specific tenure insecurity of those who cited it as the reason that does not show up well in the available measures of insecurity, since the social capital necessary to make a successful secure land contract cannot be easily measured by an outsider. In fact, the majority (23 out of 34) of adopters were on farms that were not owner operated. Clearly, some of the moral hazard problems associated with land contracting had been solved well enough on these farms to allow adoption.

The direct revelation results strengthen the weak econometric findings that resource costs push farmers to adopt resource-conserving technologies. It is possible that a majority of the farmers in the sample had a preference for drip irrigation's resource-saving qualities; it is just that the vast majority are constrained in other markets. Although the econometric evidence gives only weak support to the idea that farmers adopt to conserve resources, farmers themselves did consider it in their calculations. The farmers included in this sample were all receiving a "price shock" to their cost of water that induced them to prefer a water-conserving technology. That new preference only translated into adoption among a minority of farmers because of other constraints they faced.

### Conclusions

Environmentally sustainable development implies individual actors responding to changing natural resource stocks. Constrained individuals, however, may need some help in responding. The estimation procedure sheds some light on the relevance of the primary hypotheses on technology adoption to drip-irrigation adoption in Tunisia. The resource scarcity hypothesis is only partially validated by the econometrics, but the revealed preference data suggest that farmers do want to conserve their resources. Much stronger effects on technology adoption choices were shown by information and credit constraints. The econometric evidence of a capital constraint is reinforced by the quickest adoption of the technology taking place in areas where the technology can pay for itself in the least amount of time. The evidence for the learning-cost hypothesis is even stronger, with better-informed farmers and those closest to the technology's first introduction having a significantly increasing probability of adopting drip irrigation.

From a policy standpoint these results imply that resource price incentives, while they give proper guidance to efficient resource allocation, are insufficient when farmers face information and credit constraints. Policies that alleviate or circumvent those market imperfections may be among the most effective in promoting this resource-saving technology. The suggestion that neighborhood adoption rates can determine farmer adoption decisions warrants more specific research, since it has a direct relevance for agricultural extension efforts. The complementarity of drip irrigation and capital suggests that providing better access to credit among farmers can help speed the technology adoption process. The evidence presented here suggests that while farmers seem to be price sensitive, one cannot expect farmers to automatically respond to declines in the quality of resources by adopting new technologies without
q4 adequately operating information and credit markets.[20]

## Notes

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5. For a review of the literature, see Gershon Feder, Richard E. Just, and David Zilberman, "Adoption of Agricultural Innovations in Developing Countries: A Survey," *Economic Development and Cultural Change* 33, no. 2 (1985): 255–98.

6. Esther Boserup, *The Conditions of Agricultural Growth* (London: Allen & Unwin, 1965), provides the classic formulation of this hypothesis in describing how population pressures lead to agricultural intensification. A similar thesis informs the institutional innovation literature, e.g., Yujiro Hayami and Vernon Ruttan, *Agricultural Development: An International Perspective* (Baltimore: Johns Hopkins University Press, 1985).

7. Timothy Besley and Anne Case, "Modeling Technology Adoption in Developing Countries" (*American Economic Review* 83, no. 2 [1993]: 396–402), outline a

dynamic model showing how credit constraints impinge on the dynamic investment choice of farmers.

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10. Everett M. Roger, *Diffusion of Innovations*, 3d ed. (New York: Free Press, 1986).

11. Charles Manski, *Identification Problems in the Social Sciences* (Cambridge, Mass.: Harvard University Press, 1996).

12. In assuming that all adopters face the same market price for a technology, this is stating that the technology suppliers operate in either a fully competitive market or a fixed-price market

13. Manski; and William H. Greene, *Econometric Analysis* (New York: Macmillan, 1993).

14. Pumping costs per hectare include both the cost of pumping water from wells and payments made to the government for those farmers who had access to government-provided irrigation water through taps on their land. Within the government irrigation perimeters, prices charged per cubic meter were less than the average cost of pumping water from a well with a diesel pump. Almost all surveyed farmers with access to government-provided water also pumped water from a well.

15. The average level of salinity of 2.16 grams per liter represents a level at which many types of crops are unable to survive.

16. The Simpson Index is defined as follows: $SI = 1/\sum p_j^2$, where $p_j$ is the proportion of cultivated land area devoted to crop $j$. This Simpson’s Index takes a minimum value of one for monocropping and increases for farms with better diversification. In the sample, the maximum size is 7.2, while the average of this variable is 2.92.

17. For a discussion of this issue, see, e.g., Shira Lewin, “Economics and Psychology: Lessons for Our Own Day from the Early Twentieth Century,” *Journal of Economic Literature* 24 (September 1996): 1293–1323, quotation on 1293.

18. See Amartya K. Sen, “Internal Consistency of Choice” (*Econometrica* 61, no. 3 [May 1993]: 495–521), for a critique of the relevance of internal consistency; and Manski for critiques of the ordering of data required by internal consistency.

19. These questions were asked as open-ended questions and later coded into the categories used for analysis.

20. A final caveat is in order: drip irrigation can allow an extension of irrigated cultivation onto ever more marginal, salinated lands. Work by Farhed Shah et al., “Adoption of New Irrigation Technology” (in Hoff et al., eds., pp. 478–99), on drip-irrigation adoption in California shows that this remains a distinct possibility. The effect of reducing water requirements of plants may merely lead to an extension of

the irrigated area with no decrease in overall water usage, if not a slight increase. Without the appropriate pricing of the natural resources provided by a clear property rights system, drip irrigation, a resource-conserving technology, has the potential to cause as many problems as it solves.