

Technology Adoption Under Uncertainty: Theory and Application to Irrigation Technology

Phoebe Koundouri

Department of Economics, University of Reading, Reading, RG6 6AA, UK.
Department of Economics and CSERGE, University College London, WC1E 6BT, UK.

Céline Nauges

LERNA-INRA, Université des Sciences Sociales, 21 Allée de Brienne, 31000 Toulouse, France.

Vangelis Tzouvelekas

Department of Economics, University of Crete, 74100, Rethymno, Crete, Greece.

Abstract. We develop a theoretical model to derive the conditions under which a farmer facing production risk and incomplete information will adopt a more efficient irrigation technology. A reduced form of this model is estimated using a sample of 265 farms located in Crete, Greece. We find that production risk significantly affects the probability of technology adoption thus showing that farmers are not risk-neutral, and that they choose to adopt the new technology in order to hedge against production risk. We also show that farmer's information about the new technology plays a significant role in his decision to adopt.

JEL Classification: C25, D81, Q12.

1 Introduction

Conventional microeconomic models applied to innovations have not adequately explained the variation in technological adoption across firms. Numerous theoretical and empirical studies have attempted to explain the observed patterns of technological change, especially in agriculture, yet there is no consistent explanation why seemingly profitable technologies are sometimes not adopted by specific classes of farms. Possibly, the problem is that economic models have difficulty with the concept of heterogeneity. One of the sources of this heterogeneity may be risk preferences. The adoption of new or untried technologies always involves a degree of risk and uncertainty concerning the effect of this input on the distribution of farmers' profits. In this paper we develop a theoretical and empirical

model that aims to explain technology adoption under risk; the application of the model concerns adoption of irrigation technology in agriculture.

Irrigation water is becoming an increasingly scarce resource for the agricultural sector in many regions and countries. Common ground in past policy schemes was the development of adequate irrigation infrastructure to guarantee the supply of irrigation water as the demand for agricultural products continued to increase. However, these expansionary policies have resulted in increased consumption of irrigation water by the agricultural sector at a significant cost and physical scarcity. Water scarcity has become an increasing social and economic concern for the policy makers and competitive water users. Particularly, agriculture is becoming the sector to which policy makers are pointing out at the core of the water problem. The use of modern irrigation technologies has been proposed as one of several possible solutions to the problem of water resource scarcity and environmental degradation in many agricultural areas around the world.

The empirical research on this issue followed, however, different tracks. Based on technical grounds several studies have attempted to analyze on-farm adoption of irrigation technologies using the engineering notion of irrigation water efficiency defined by Whinlesey, McNeal and Obersinner (1986) (i.e., ratio of water stored in the crop root zone to the total water diverted for irrigation). Moreover, by technically and economically evaluating irrigation technologies, some combinations of water savings and yield increase was found to be necessary in order to induce farmers to adopt water conserving technologies (e.g., Coupal and Wilson, 1990; Santos, 1996; Droogers, Kite and Murray-Rust, 2000, Arabiyat, Segarra and Johnson, 2001). Despite of the fact that these studies have been quite appealing in analyzing the changes and the diffusion of irrigation technologies in agriculture they lack economic intuition.

On the other hand, in the context of technological adoption models initiated by

Griliches (1957) pioneering work on adoption of hybrid corn in the US, the analysis of farmer's decision to adopt technological innovations took a different direction. The majority of this group of empirical research has been concerned with the socio-economic, demographic and structural factors that determine farmer's choice to adopt or not irrigation technologies and with patterns of diffusion of the innovation through the population of potential adopters over time (e.g., Fishelson and Rymon, 1989; Dinar and Zilberman, 1991; Dinar, Campbell and Zilberman, 1992; Dinar and Yaron, 1992).

Despite of the numerous studies in this area, the results of applied research are often contradictory concerning the importance and influence of any given variable used to analyze farmer's decision. Among the various socio-economic, structural or demographic variables used in these studies, risk has often been considered as a major factor reducing the rate of adoption of any kind of innovation (Jensen, 1982). Nevertheless, the issue of risk has been rarely addressed adequately in the relevant literature. Uncertainty associated with the adoption of any kind of agricultural technology has two features: first, the perceived riskiness of future farm yield after adoption and second, production or price uncertainty related to farming itself.

Several authors have empirically investigated technology adoption and diffusion taking into account farmer's perception about the degree of risk concerning future yield (e.g., Tsur, Sternberg and Hochman, 1990; Feder and Umali, 1993; Saha, Love and Schwart, 1994; Batz, Peters and Janssen, 1999). In particular, Saha, Love and Schwart (1994) identify the factors that affect technology adoption and its intensity, under incomplete information dissemination and output uncertainty. Their results emphasize the role of information (and education) in the adoption of emerging technologies. Nevertheless they explicitly assume that farmer's profits are non-random in the absence of adoption and therefore in their theoretical framework they assume that neither the riskiness of the

new technology nor the farmer's attitude towards risk affect adoption decisions. It seems therefore that a relative dearth of research exists on the perceivable link between farmer's decision to adopt innovations and production or price uncertainty related to agricultural production. A notable exception is the work by Yaron, Dinar and Voet (1992) who attempted to analyze the effect of price uncertainty on the innovativeness of family farms in the Nazareth region of Israel, by including in their technology adoption model a proxy of farmer's risk tolerance towards output price variability. Finally, Kim and Chavas (2003) investigate the dynamic effects of technological progress (as measured by a time trend) on risk exposure, through calculation of conditional moments of yield and profit from a panel data on corn production from Wisconsin. Their results indicate that technological progress contributes to reducing the exposure to risk as well as downside risk, over time, although these effects vary across space.

The present paper contributes to this literature by testing how production risk and incomplete information affect the probability that a farmer adopts a new, more efficient, irrigation technology. Specifically we extend Saha, Love and Schwart (1994) theoretical framework by explicitly introducing risk in adoption versus non-adoption decisions. In arid and semi-arid regions where water is a primary input in the production process, production of each farm (and thus profit) may become random because of randomness in climatic conditions. A structural model defining the condition of adoption under farmer's risk aversion and incomplete information about the new technology is theoretically derived. A reduced form of this model is then estimated using a randomly selected sample of 265 farms located in Crete, Greece. Following Antle (1983, 1987) and Antle and Goodger (1984), we propose a flexible representation of uncertainty by using moments of the profit distribution as determinants of farmer's decision regarding adoption of new irrigation technology. The empirical analysis provides new evidence on the link between production

risk and technology adoption. In particular, we show that the probability of adoption increases for farmers who experience higher variance of profit and higher variability in the variance of their profit (approximated by the fourth moment of profit, kurtosis), thus showing that farmers are willing to adopt in order to hedge against production risk. We also prove that better information on new equipment/technologies may induce farmers to adopt earlier.

These results provide guidance to policy makers contemplating the introduction of economic instruments, in order to create incentives for adoption of water-conservation technologies. In particular, they indicate that policy makers should incorporate in the relevant cost-benefit analysis, the expected benefits that farmers derive from the reduction in their production risk, which will be caused by adoption. Moreover, the results show that in addition to the use of economic instruments for creating incentives that induce faster diffusion of new water-efficient technologies, the provision of technology-related information, has the same effect by reducing the option value associated with adoption. Hence, the policy maker may use information-provision to induce faster diffusion of adoption among farmers.

The rest of the paper is organized as follows. In section 2 we present the theoretical framework used to analyze farmer's decision in the presence of production risk and incomplete information about the new technology. In section 3 we describe the data used in the estimation of the empirical model and introduce the relevant estimation procedure. In section 4 we present and analyze the empirical results, while in section 5 we conclude by deriving some policy recommendations.

2 Theoretical model

In this section, we develop the production model, which describes the behavior of the representative agent under risk. The farmer is assumed to be risk-averse and to produce a single output q . Let p denote output price, $f(\cdot)$ the production function, assumed continuous and twice differentiable, X the vector of inputs, and r the corresponding vector of input prices. The farmer is assumed to incur production risk, as crop yield might be affected by climatic conditions. This risk is represented by a random variable ε , whose distribution $G(\cdot)$ is exogenous to farmer's actions. This is the only source of risk we consider, as prices p and r are assumed non-random¹ and farms are assumed to be price-takers both in the input and output markets.

Water (input X_w) is assumed to be an essential input in the production process. Efficiency in water use, assumed to vary between farms, is captured by incorporating parameter $h(\alpha)$ in the production function, where α is a vector of farmer's characteristics. The production function will thus be written $q = f[h(\alpha)X_w, X_{-w}]$, where X_{-w} is the vector of all inputs except water.

Allowing for risk aversion, the farmer's problem is to maximize expected utility of profit:

$$\max_X E[U(\Pi)] = \max_X \int [U(pf(\varepsilon, h(\alpha)X_w, X_{-w}) - r'X)] dG(\varepsilon), \quad (1)$$

where $U(\cdot)$ is the Von Neuman-Morgenstern utility function. Given that p and r_w are not random, the first-order condition for irrigation water input X_w is:

$$\begin{aligned} E[r_w \times U'] &= E \left[p \frac{\partial f(\varepsilon, h(\alpha)X_w, X_{-w})}{\partial X_w} \times U' \right] \\ \Leftrightarrow \frac{r_w}{p} &= E \left(\frac{\partial f(\varepsilon, h(\alpha)X_w, X_{-w})}{\partial X_w} \right) + \frac{\text{cov}(U', \partial f(\varepsilon, h(\alpha)X_w, X_{-w})/\partial X_w)}{E(U')}, \end{aligned} \quad (2)$$

where $U' = \partial U(\Pi)/\partial \Pi$. For a risk-neutral producer, the ratio of input price over output price, r_w/p , equals the expected marginal productivity of X_w , $E[\partial f(\varepsilon, h(\alpha)X_w, X_{-w})/\partial X_w]$.

When the producer is risk-averse, the second term in the right-hand side of (2),

$$cov(U', \partial f(\varepsilon, h(\alpha)X_w, X_{-w}) / \partial X_w) / E(U'),$$

is different from zero, and measures deviations from the risk-neutrality case. More precisely, this term is proportional and has the opposite sign, to the marginal risk premium with respect to X_w .

We now incorporate in our model the decision to adopt a new irrigation technology. This decision is modeled as a binary choice, where the farmer can choose to adopt ($i = 1$) or not ($i = 0$) an innovative irrigation technology. This technology increases water use efficiency ($h_1(\alpha) > h_0(\alpha)$ for $0 < \alpha < 1$), that is, if the farmer uses the new technology, less water will be necessary to produce the same level of output. We assume for now that there is no uncertainty underlying the use of the new equipment, i.e. that future costs and benefits are perfectly known at the time of adoption. Adopting the new technology implies a fixed cost ($I_1 > 0$ and $I_0 = 0$) and might change the marginal cost of water ($r_w^1 \neq r_w^0$). Denote X^1 (respectively, X^0) the optimal input choices if the new technology is (respectively, is not) adopted. Thus, the first order condition for water input corresponding to the case of adoption is:

$$\frac{r_w^1}{p} = E \left(\frac{\partial f(\varepsilon, h_1(\alpha)X_w^1, X_{-w}^1)}{\partial X_w} \right) + \frac{cov(U', \partial f(\varepsilon, h_1(\alpha)X_w^1, X_{-w}^1) / \partial X_w)}{E(U')}, \quad (3)$$

and for the case of non-adoption:

$$\frac{r_w^0}{p} = E \left(\frac{\partial f(\varepsilon, h_0(\alpha)X_w^0, X_{-w}^0)}{\partial X_w} \right) + \frac{cov(U', \partial f(\varepsilon, h_0(\alpha)X_w^0, X_{-w}^0) / \partial X_w)}{E(U')}. \quad (4)$$

The farmer will adopt the new irrigation technology if the expected utility with adoption is greater than the expected utility before adoption, i.e.

$$E[U(\Pi^1)] - E[U(\Pi^0)] > 0, \quad (5)$$

where

$$E [U(\Pi^1)] = \int [U(pf(\varepsilon, h_1(\alpha)X_w^1, X_{-w}^1) - r_w^1 X_w^1 - r'_{-w} X_{-w}^1 - I_1)] dG(\varepsilon), \quad (6)$$

and

$$E [U(\Pi^0)] = \int [U(pf(\varepsilon, h_0(\alpha)X_w^0, X_{-w}^0) - r_w^0 X_w^0 - r'_{-w} X_{-w}^0)] dG(\varepsilon) \quad (7)$$

are respectively, the expected utility with adoption and without adoption. As the new technology is more water-efficient, we would expect risk-averse farmers who bear higher profit uncertainty to have a higher probability of adoption, in order to hedge against the risk of adverse climatic conditions.

Assume now that future profit flows after adoption are not known with certainty. In this case, and as buying the new irrigation technology implies sunk costs (there is a fixed cost of investment and some irreversibility in the decision as it might not be easy to re-sale the equipment), there may exist a positive value of information (see Dixit and Pindyck, 1984). In other words, farmers may prefer to delay adoption in order to get more information on the new equipment. Consequently, there may exist an additional premium entering the condition of adoption. The farmer will adopt if:

$$E [U(\Pi^1)] - E [U(\Pi^0)] > VI, \quad (8)$$

where $VI (VI \geq 0)$ represents the value of information for the representative farmer, which should depend on the fixed cost of investment, the level of uncertainty related to the use of the new technology, and farmer's characteristics.

3 Data and estimation procedure

3.1 Data Description

The data set used in this study is extracted from a broader data set, collected via a survey on the structural characteristics of the agricultural sector in Crete, financed by the Re-

gional Directorate of Crete in the context of the Regional Development Program 1995-99 (Lioudakis, 2000). The sample is a cross-section of 265 randomly selected farms located in the four major districts of Crete, namely Chania, Rethymno, Heraklio and Lasithi, during the 1995-96 period. The survey provides detailed information about production patterns, input use, average yields, gross revenues, structural characteristics and the number of farms which adopted modern irrigation technologies. In the sample, 87 out of 265 farms (32.8%) adopted modern irrigation technologies, quite recently.² These technologies vary from simple sprinklers applied mainly to tree crops, to greenhouse integrated systems that control the irrigation of the plantation. Descriptive statistics are provided in Table 1.

[insert Table 1 around here]

The adopting farms are of smaller size (45 stremmas or 4.5 ha on the average) and with lower capital stock (2,634 euros). Although, farms adopting new irrigation technologies have lower profits compared with their non-adopters counterparts (17,087 and 20,673 euros, respectively), they exhibit higher average profitability per stremma 380.1 and 370.2 euros/stremma, respectively. Finally, the average irrigation water use per stremma is 2.8 and 3.3 m³ for adopters and non-adopters, respectively.

In Table 1 we also present information on socio-economic and structural characteristics of the surveyed farms. From the data presented, it is evident that older farmers, who are in general less educated than their younger counterparts, are not adopting new technologies as eagerly. The average age and education level of farmers that adopted modern irrigation technologies is 36 years of age and 11 years in schooling, respectively, whereas for farmers using traditional technologies the corresponding values are 56 and 6 years. Furthermore, farms with higher debts and received subsidies, are more likely to have adopted new irrigation technologies. It is also interesting to note that average debt for adopting farms is 2,921 euros, whereas the corresponding figure for farms that are using traditional irrigation

practices is only 893 euros. Similarly the level of subsidies is also almost three times the level of subsidies for innovative farms (1,194 and 444 euros, respectively). Although subsidies refer mainly to direct income transfers from CAP (common agriculture policy) and thus are not related with farmers' adoption process, it seems that they provide farmers with the financial viability necessary for investing in new technologies.

Another interesting point that arises from the data presented in Table 1, refers to the exposition of farmers to extension services (private or public) and their access to general farming information. Specifically, farmers adopting new irrigation technologies are visited by extension agents on average nine times during the cropping year, whereas farmers insisting on traditional irrigation technologies are visited only two times on average. Further, farmers that adopt new technologies have better access to farming related information from various sources (e.g. newspapers, television and radio, visits to agricultural product fairs and shows, sporadic attendance of seminars, meetings or demonstrations and so on). Finally, farms enjoying less favorable environmental conditions seem to be among the adopters of new irrigation technologies; that is farms facing higher average annual temperature and/or lower annual precipitation have on average adopted new irrigation technologies more intensively.

3.2 The estimation procedure

The condition defining adoption is given by:

$$E [U(\Pi^1)] - E [U(\Pi^0)] - VI > 0.$$

At the time of the survey we observe farmers in a unique situation (adoption or non-adoption), hence we cannot estimate this structural equation. Instead, we estimate a reduced-form of this equation and we focus on the impact of risk to explain adoption decision.

First, in order to avoid specifying a functional form for the probability function of profit $\Pi(\cdot)$, the distribution of risk $G(\cdot)$, and for farmer's risk preferences (i.e. the utility function $U(\cdot)$), we use a moment-based approach which allows a flexible representation of the uncertainty (Antle, 1983, 1987; Antle and Goodger, 1984). Production risk and thus profit uncertainty are accounted for in the adoption model by using the sample moments of the profit distribution as explanatory variables of farmer's decision. Our data-set has the great advantage of gathering information on farmers who just adopted the new irrigation technology. In other words, most of the farmers were surveyed at the time the decision of adoption/non-adoption was made. Thus the profit function has not yet been affected by the adoption decision and for this reason, moments of profit can be assumed exogenous to the adoption decision. Second, as explained in the theoretical section, there exists an additional source of risk that derives from uncertainty on future profit flows, which is introduced in the production process through the use of the new equipment. The cost of this uncertainty is represented by a premium, indicating the value of information (VI), in the above equation. In our empirical model, the role of information on the adoption decision will be measured through the following proxy variables: education level of the farmer, general access to information, and number of extension visits, all three variables assumed to be positively correlated with farmer's information on the new equipment. As argued by Saha *et al.* (1994), if diffusion of technology-related information is partly based on publications or reports, "an adopter's information depends on individual-specific attributes, the most important being education".

The estimation procedure follows two steps. First, we compute the first four sample moments of the profit distribution of each farmer. Second, we incorporate the estimated moments in a traditional discrete choice model, along with other farmer's characteristics and the variables related to farmer's information, to analyze how production risk and

information affects the decision to adopt a technological innovation.

The first four moments of the profit distribution are derived following a sequential estimation procedure (see Kim and Chavas, 2003 for a detailed description of the procedure). In the first step, profit is regressed on the contemporaneous input variables to provide an estimate of the ‘mean’ effect. The model is the following:

$$\Pi_i = f_1(X_i, W_i, \beta_1) + u_{1i}$$

where i indices individual farmers, Π is the profit per hectare, X is the vector of variable inputs (labour, intermediate inputs, and water),³ and W is the vector of extra shifters including farmer’s characteristics (farmer’s age and farmer’s supplementary revenue unrelated to farming activities), and farm-specific characteristics (geographical location⁴ and aridity). u_{1i} is the usual error term, assumed of mean zero. Under the exogeneity assumption of the explanatory variables (X, W), the Ordinary Least Squares (OLS) produce consistent and efficient estimates of parameters β_1 .

The j^{th} central moment of profit conditional on X is defined as $\mu_j(X) = E[(\Pi(X) - \mu_1)^j]$, for $j = 1, \dots, m$, where μ_1 represents the mean profit or the first moment of profit. Thus, the estimated errors from the mean effect regression ($e = \Pi - f_1(X, W, \hat{\beta}_1)$) are estimates of the first central moment of the profit distribution.

The estimated errors e are then squared and regressed in turn on the same set of explanatory variables:

$$e_i^2 = f_2(X_i, W_i, \beta_2) + u_{2i}. \tag{9}$$

The application of OLS on (9) provides consistent estimates of β_2 (Antle, 1983) and the predicted values \hat{e}_i^2 are consistent estimates of the second central moment of the profit distribution (the variance). We follow the same procedure to estimate the third and fourth central moments, by using the estimated errors (e) raised to the power of three

and four, respectively, as the dependent variables in the estimated models.⁵ Even though most distribution functions are well approximated by their first three moments (Antle and Goodger, 1984), we proceed to the estimation of the fourth moment, which provides a measure of the variability of profit variance, a measure that might be relevant for farmer's selection of production inputs. The four estimated moments are then incorporated in the discrete model of technology adoption along with farmer's characteristics, and in particular the three variables measuring information at the farm-level.

Recall from section 2 that the farmer will choose to adopt the innovate irrigation technology if $Y_i^* \equiv E[U(\Pi_i^1)] - E[U(\Pi_i^0)] - VI > 0$. Y_i^* is an unobservable random index for each farmer that defines their propensity to choose to adopt a new irrigation technology. For purposes of estimation, this index can be expressed as:

$$Y_i^* \equiv Z_i' \alpha + v_i > 0 \quad (10)$$

where Z_i is the vector of regressors, α is a vector of parameters to be estimated and v_i is an error term. The binary choice is defined by assuming a probability density function for v_i and letting the random variable $Y_i = 1$ if $Y_i^* > 0$ and $Y_i = 0$ if $Y_i^* \leq 0$. Equation (10) will be estimated using a Probit model; i.e. assuming a cumulative distribution function $F(Z_i' \alpha) = \int_{-\infty}^{Z_i' \alpha} \frac{1}{\sqrt{2\pi}} v^{-t^2/2} dt$. As we incorporate estimated values in the Probit equation (and not observed values), we use bootstrapping techniques to correct for standard errors in the Probit model.

4 Estimation results

Table 2 reports the effects of all variables on the decision to adopt new irrigation technologies. In general, the signs of the explanatory variables in the Probit model conform to our expectation that the farmers who bear more risk are more likely to adopt the new, water-saving, irrigation technology. The rejection of risk-neutrality is shown through

the significance of the direct effect of three (first, second and fourth) out of four sample moments, which were included in the estimated adoption model.

[insert Table 2 around here]

Risk is found to play a prominent role in the decision to adopting a new technology. Risk associated with the environmental characteristics of the farm is found to be important. Higher aridity as well as sandy soils,⁶ both increasing the water requirements of production and thus increasing the production risk related to adverse climatic conditions (such as droughts), induce farmers to adopt new technologies with greater water-saving potential. Farmer's own characteristics are also highly significant in the choice of adopting new irrigation equipment. We show that the younger and the more educated the farmer is, the higher the probability that he will adopt new irrigation technologies. The educational effect as well as the positive signs associated with the variables describing exposition of farmers to extension services and access to general farming information may indicate that there exists a non-zero (positive) value on waiting for better information (Dixit and Pindyck, 1984). In other words, the farmers who have better access to information (through visits, general information channels, or education) put a lower value on the option to wait and for this reason adopt earlier than other farmers (i.e. they have a higher probability to adopt the new technology at the time of the survey with respect to less informed farmers).

The central role of risk in farmer's decision is emphasized through the significance of the sample moments. The first and second moments, which approximate respectively expected profit and profit variance are highly significant. The third moment, which approximates the skewness of profit, is not statistically significant, while the fourth moment is significant at the 10% level. These results indicate that the higher the expected profit the greater the probability that a farmer decides to adopt a new irrigation technology, as

he expects to be able to afford the adoption of new water-saving technologies. Moreover, the greater the variance of profit (and the greater the variance of variance) the greater the probability to adopt new irrigation technologies, which allows them to save water and decrease their production (yield) risk arising from water crop requirements. This result provides evidence that farmers invest in new technologies as a means to hedge against input related production risk. Finally, the statistical insignificance of the third moment of profit, indicates that farmers are not taking downside yield uncertainty into account when they decide whether to adopt a new irrigation technology or not. That is, while the choice of irrigation technology is relevant in dealing with production risk (as measured by the variance of yield), these results suggest that technology choice does not affect exposure to downside yield uncertainty. Following Kim and Chavas (2003), we can test for the nature of the exposure to downside risk. More precisely, we can test the null hypothesis that the profit distribution is symmetric, using a Wald statistic. The skewness coefficient measuring symmetry of the distribution is defined as $s = (\mu_3)^2 / (\mu_2)^3$ where μ_j is the j^{th} central moment of profit. Under the null hypothesis of symmetry ($s = 0$), the test statistic $W = N(\hat{s}/6)$ (where N is the number of farmers) is distributed as a $\chi^2(1)$. If the null hypothesis of symmetry is rejected then we will have evidence that the distribution of profit is skewed to the left (corresponding to a significant exposure to downside yield risk). We test for symmetry at the sample mean, and at the mean of various sub-samples: the sub-sample of adopters and of non-adopters, and sub-samples defined by geographical location of farmers (sub-sample of farmers located in Chania, Heraklio, Rethymno and Lasithi). In all cases but one (the sub-sample of the farmers located in Rethymno), we cannot reject the null of symmetry in the profit distribution. These results might explain the non-significance of the third sample moment in the adoption model.

One useful expedient when undertaking a Probit analysis is to calculate the value of the derivatives at the mean values of all the independent variables in the sample. The motivation is to display the derivative for a “typical” element of the sample. These derivatives are reported in Table 3 and represent the marginal effect of each regressor, which approximates the change in the probability of adoption at the regressors’ mean. Once again, standard errors were obtained using block resampling techniques, which entails grouping the data randomly in a number of blocks of five farms and reestimating the model leaving out each time one of the blocks of observations and then computing the corresponding standard errors (Politis and Romano, 1994).

[insert Table 3 around here]

As indicated in Table 3, the sample moments of the profit distribution, in particular mean and variance, affect the decision of the farmer to adopt a new technology thus confirming that farmers are not risk-neutral. Farmer’s information, as measured by his education level, his access to information, and extension visits, is also found highly significant, thus reinforcing the idea that the option value (or value of waiting to get better information) may play an important role in farmer’s decision.

5 Conclusions

In this paper we develop a theoretical model to describe irrigation technology adoption by farmers facing production risk and incomplete information about the new technology. The condition of adoption is derived under the assumptions of farmer’s risk-aversion, and assuming that uncertainty can come from two sources: randomness in climatic conditions and uncertainty of future profit flows associated with the use of the new technology. We estimate a reduced form of this equation using a randomly selected sample of 265 farms

located in Crete, Greece. The estimation procedure is developed in two steps. The first four moments of the profit distribution are estimated first and are then incorporated in the technology adoption model. Risk is found to play a central role in farmers' decision first through the direct effect of the sample moments of the profit distribution in the adoption model, and second through the role of information in the decision to adopt.

These results have important policy implications. Firstly, adoption of new, water-conserving irrigation technologies can be used as a means for production risk management. Secondly, if farmers are risk averse, the value of the marginal product of variable inputs exceeds their market price. This result might be used to argue (erroneously) that farms are not efficient in allocating their variable inputs and that regulation regarding input choices is needed. Neglecting risk considerations when assessing impacts of regulation policies on input choices and expected profit, could provide misleading guidance to policy makers. This is a significant piece of warning to all policy makers that contemplate regulation of stochastic production process in general, and agriculture, in particular. Thirdly, when a policy maker is contemplating the introduction of economic instruments (e.g. subsidies) in order to give incentives for adoption of water-conservation technologies, he should incorporate in the relevant cost-benefit analysis the expected benefits that farmers derive from the reduction in their production risk, which will be caused by adoption. Ignoring these benefits might result in potentially welfare-enhancing policies not satisfying a cost-benefit criterion. Finally, when the effect of a new technology on future profit flows is uncertain to the farmers, provision of adoption-related information induces faster diffusion of adoption among farmers, by reducing the option value of adoption.

Endnotes

¹ Since farms in the sample are located in a relative small geographic area, output and factor price variability is low. In addition farmers have a minimum guaranteed price under relevant regulations. That is, if the market output price, in any particular year, is lower than the minimum guaranteed price, farmers will receive a lump-sum, which will subsidize per unit production by the difference between the minimum guaranteed price and the market price (Huffman and Mercier, 1991).

² Note that the fact that farmers have been interviewed just after adoption will be crucial in the subsequent empirical analysis.

³ We choose a flexible functional form for f_1 which includes inputs in levels, squares and cross-variables.

⁴ We control for farm location among the four districts, namely Chania, Rethymno, Heraklio, and Lasithi.

⁵ Estimation results are not reported here but are available upon request.

⁶ Crop production on sandy soils is more water intensive, as they have higher absorbing capacity than other types of soil.

References

- [1] Antle, J., 1983. Testing the Stochastic Structure of Production: A Flexible Moment-Based Approach. *J. of Bus. and Eco. Stat.* 1, 192-201.
- [2] Antle, J., 1987. Econometric Estimation of Producers' Risk Attitudes. *Am. J. of Agr. Econ.*, 509-522.
- [3] Antle, J.M., and W.A. Goodger, 1984. Measuring Stochastic Technology: The Case of Tulare Milk Production". *Am. J. of Agr. Econ.* 66, pp. 342-350.
- [4] Arabiyat, T.S., Segarra, E. and J.L. Johnson, 2001. Technology Adoption in Agriculture: Implications for Ground Water Conservation in the Texas High Plains. *Res. Cons. Rec.* 32, pp. 147-156.
- [5] Ball, V.E., Bureau, J.C., Butault, J.P. and R. Nehring, 2001. Levels of Farm Sector Productivity: An International Comparison. *J.Prod. Anal.* 15, pp. 5-29.
- [6] Batz F.-J., Peters, K. J. and W. Janssen, 1999. The Influence of Technology Characteristics on the Rate and Speed of Adoption. *Agr. Econ.* 21, pp. 121-130.
- [7] Coupal, R.H., and P.N. Wilson, 1990. Adoption Water-Conserving Irrigation Technology: The Case of Surge Irrigation in Arizona. *Agr. Wat. Man.* 18, pp. 15-28.
- [8] Dinar, A., Campbell, M.B. and D. Zilberman, 1992. Adoption of Improved Irrigation and Drainage Reduction Technologies under Limiting Environmental Conditions. *Env. Res. Econ.* 2, pp. 360-373.
- [9] Dinar, A., and D. Yaron, 1992. Adoption and Abandonment of Irrigation Technologies. *Agr. Econ.* 6, pp. 315-332.

- [10] Dinar, A., and D. Zilberman, 1991. The Economics of Resource-Conservation, Pollution-Reduction Technology Selection: The Case of Irrigation Water. *Res. Ener.* 13, pp. 323-348.
- [11] Dixit, A. K., and R. S. Pindyck, 1994. *Investment Under Uncertainty*, Princeton N.J.: Princeton University Press.
- [12] Droogers, P., Kite, G. and H. Murray-Rust, 2000. Use of Simulation Models to Evaluate Irrigation Performance Including Water Productivity, Risk and System Analyses. *Irrig. Sci.* 19, pp. 139-145.
- [13] Feder, G., and D. L. Umali, 1993. The Adoption of Agricultural Innovations: A Review. *Techn. For. and Soc. Ch.* 43, pp. 215-239.
- [14] Fishelson, G. and D. Rymon, 1989. Adoption of Agricultural Innovations: The Case of Drip Irrigation of Cotton in Israel. *Tech. For. Soc. Ch.* 35, pp. 375-382.
- [15] Griliches, Z., 1957. Hybrid Corn: An Exploration in the Economics of Technological Change. *Econometrica* 25, pp. 501-523.
- [16] Groom, B., Koundouri, P., Nauges, C., and A. Thomas, 2002. Stochastic Technology and Risk Attitudes in Agricultural Production. *World Congress of Environmental and Resource Economics*, Monterey, USA.
- [17] Huffman, W.E., and S. Mercier, 1991. Joint Adoption of Microcomputer Technologies: An Analysis of Farmers' Decision. *The Rev. of Eco. and Stat.* 73(3), pp. 541-546.
- [18] Jensen, R., 1982. Adoption and Diffusion of an Innovation of Uncertain Profitability. *J. Econ. Th.* 27, pp. 182-192.

- [19] Kim, K., and J.P. Chavas, 2003. Technological change and risk management: an application to the economics of corn production. *Agr. Eco.* 29, pp. 125-142.
- [20] Liodakis, G., 2000. *The Cretan Agricultural Sector: Structural Problems and Future Prospects*. Chania: TUC Press (in Greek).
- [21] Politis, D., and J. Romano, 1994. Large Sample Confidence Regions Based on Subsamples Under Minimal Assumptions. *Ann. Stat.* 22, pp. 2031-2050.
- [22] Tsur, Y., Sternberg, M. and E. Hochman, 1990. Dynamic Modeling of Innovation Process Adoption with Risk Aversion and Learning. *Oxf. Econ. Pap.* 42, pp. 336-355.
- [23] Saha, A., Love, A.H. and R. Schwart, 1994. Adoption of Emerging Technologies Under Output Uncertainty. *Am. J. Agr. Econ.* 76, pp. 386-846.
- [24] Santos, F.L., 1996. Evaluation and Adoption of Irrigation Technologies: Management-Design Curves for Furrow and Level Basin Systems. *Agr. Syst.* 52, pp. 317-329.
- [25] Whinlesey, N., McNeal, B. and V. Obersinner, 1986. Concepts Affecting Irrigation Management, in *Energy and Water Management in Western Irrigated Agriculture*, N. Whinlesey (ed.), Boulder: Westview Press.
- [26] Yaron, D., Dinar, A. and H. Voet, 1992. Innovations on Family Farms: The Nazareth Region in Israel. *Am. J. Agr. Econ.* 74, pp. 361-370.

Tables

Table 1: Descriptive statistics

Variable	Adopters	Non-Adopters
<u>Economic Data:</u>		
Crop Output (in Kgs)	18,234	21,439
Livestock Output (in Kgs)	1,542	2,504
Land (stremmas ¹)	45	56
Labour (in hours)	452	530
Chemical Inputs (in Kgs)	12,405	16,212
Capital Stock ² (in Euros)	2,634	3,247
Irrigation Water (in m ³)	140	176
<i>Total Cost (in Euros)</i>	<i>36,189</i>	<i>45,198</i>
<i>Total Revenue (in Euros)</i>	<i>53,276</i>	<i>65,871</i>
<i>Profits (in Euros)</i>	<i>17,087</i>	<i>20,673</i>
<u>Farm Characteristics:</u>		
Farmer's Age (years)	36	56
Farmer's Education (years)	11	6
Farm's Debts (in Euros)	2,921	893
Subsidies (in Euros)	1,194	444
Extension Visits (No visits)	9	2
Access to Information (1=yes, 0=no)	0.471	0
Aridity Index ³	1.188	0.603
Soil type: (% of farms)		
Clayey Sandy	10.3	41.0
Clayey Limestones	40.2	19.7
Marly Limestones	41.4	15.7
Dolomitic Limestones	8.0	23.6
Number of Farms	87	178

Notes:

¹ One stremma equals 0.1 hectare (ha).

² Capital stock was estimated using the perpetual inventory method as described in Ball et al. (2001).

³ Aridity index is defined as the ratio of the average annual temperature in the area over total annual precipitation.

Table 2: Parameter Estimates of the Irrigation Technology Adoption Model

Variable	Estimate	T-ratio ¹	Variable	Estimate	T-ratio
Constant	-5.1503	(4.7474)	<i>Location Dummies:</i>		
Age	-0.1257	(5.3412)	Rethymno	0.2293	(0.2792)
Education	0.2597	(3.7792)	Heraklio	0.7070	(2.1596)
Aridity Index	0.4119	(4.5948)	Lasithi	0.2225	(3.1340)
Farms' Debts	0.0013	(5.7274)	<i>Profit Moments:</i>		
Extension Visits	0.1051	(2.4017)	1st Moment	0.2950	(3.0628)
Access to Information	0.1834	(3.9865)	2nd Moment	0.6850	(2.1008)
Off-farm Income	-0.0575	(2.2520)	3rd Moment	-0.3113	(0.9311)
Family Farming	-0.0430	(2.0394)	4th Moment	0.0983	(1.7295)
<i>Soil Dummies:</i>					
Clayey Sandy	0.2022	(2.6544)			
Clayey Limestones	0.3134	(1.9815)			
Marly Limestones	0.9557	(1.1232)			
% of Correct Prediction	94.52				
Mc Fadden's R2	91.02				

¹ Standard errors were obtained using block resampling techniques which entails grouping the data randomly in a number of blocks of ten farms and reestimating the model leaving out each time one of the blocks of observations and then computing the corresponding standard errors (Politis and Romano, 1994).

Table 3: Marginal Effects of the Explanatory Variables

Variable	Estimate	T-ratio ¹	Variable	Estimate	T-ratio ¹
Age	-0.00931	(6.1241)	<i>Location Dummies:</i>		
Education	0.02361	(4.0266)	Rethymno	0.00033	(0.7488)
Aridity Index	0.04337	(3.7458)	Heraklio	0.01200	(2.7418)
Farms' Debts	0.00013	(6.0247)	Lasithi	0.02365	(2.9281)
Extension Visits	0.01758	(2.2319)	<i>Profit Moments:</i>		
Access to Information	0.00342	(4.4269)	1st Moment	0.03910	(3.7418)
Off-farm Income	-0.01036	(1.9214)	2nd Moment	0.02145	(1.9674)
Family Farming	-0.00741	(1.8574)	3rd Moment	-0.01125	(0.8517)
<i>Soil Dummies:</i>			4th Moment	0.00254	(1.9685)
Clayey Sandy	0.00212	(3.0748)			
Clayey Limestones	0.00140	(2.0257)			
Marly Limestones	0.00417	(1.0415)			

1: Computed using bootstrapping techniques.