Endogenous Technology Adoption Under Production Risk: Theory and Application to Irrigation Technology

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Abstract. The main objective of this paper is to present a theoretical framework that conceptualizes technology adoption as a decision process involving information acquisition by farmers who face yield uncertainty and vary in their risk preferences. This is done by integrating the microeconomic foundations used to analyze production uncertainty at the farm level with the traditional technological adoption models. First we follow the approach of Antle (1987) based on higher-order moments of profit, which enables flexible estimation of the stochastic technology without ad hoc specification of risk preferences. Then individual risk preferences are derived, which are then used to explain farmer's decision to adopt modern water saving technologies. The proposed model is applied to a randomly selected sample of 265 farms located in Crete, Greece. Results show that risk preferences affect the probability of adoption and provide evidence that farmers invest in new technologies as a means of hedging against input related production risk.

Keywords: risk attitudes, technology adoption, stochastic agricultural production, moments-based estimation.

1 Introduction

Conventional microeconomic models applied to innovations have not adequately explained the vaiation in technological adoption across frims. Numerous theoretical and empirical studies have attempted to explain the observed patterns of technological change, especially in agiculture, 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. There is considerable heterogeneity of farms with regard to demand of new technologies, but it has been difficult to develop robust models that describe the source or consequences of this heterogeneity. One of the sources of this heterogeneity is 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 endogenous technology adoption under production 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 of 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 with the farming itself.

Several authors have empirically investigated technology adoption and diffusion taking into account farmer's perceptions 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). However, a relative dearth of research seems to exist 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.

Risk considerations are necessary in the analysis of the agricultural sector as there exist a number of possible cases where intelligent policy formulation should consider not only the marginal contribution of input use to the mean of output, but also the marginal reduction (increase) in the variance of output. The traditional approach (theoretical and empirical) to evaluating the impact of the choice of inputs on production risk makes implicit, if not explicit assumptions to the effect that inputs increase risk. Examples of such theoretical studies are Stiglitz (1974), Batra (1974) and Bardhan (1977). These studies utilized multiplicative stochastic specifications, which are restrictive in the sense that inputs that marginally reduce risk are not allowed. Just and Pope (1978) who identified this restrictiveness, proposed a more general stochastic specification of the production function which includes two general functions: one which specifies the effects of inputs on the mean of output and another on its variance, thus allowing inputs to be either risk-increasing or risk-decreasing.

While Just and Pope's model is a generalization of the traditional model, as it does not restrict the effects of inputs on the variance to be related to the mean, Antle (1983, 1987) has shown that it does restrict the effects of inputs across the second and higher moments in exactly the way traditional econometric models do across all moments. Thus Antle's departure point was to establish a set of general conditions under which standard econometric techniques can be used to identify and estimate risk attitude parameters as part of a structural econometric model, under less restrictive conditions. More specifically, Antle's moment-based approach begins with a general parameterization of the moments of the probability distribution of output, which allows more flexible representations of output distributions and allows the identification of risk parameters. Moreover, Antle's approach places the emphasis on the distribution of risk attitudes in the population, which constitutes a departure from existing literature which focuses on measurement of the risk attitudes of the individual producer (see for example Hazell, 1982; Pope, 1982; and Binswanger, 1982).

Love and Buccola (1991, 1999) also proposed an extension of Just and Pope's model including producers attitude toward risk in the model. They considered producers' risk preferences in a joint analysis of input allocation and output supply decisions. An implicit form of the utility function was assumed. In a recent article by Kumbhakar (2002), risk preference functions are derived without directly assuming an explicit form of the utility function. Two sources of risk, viz., production uncertainty and technical efficiency, are considered.

The main objective of this paper is to present a theoretical framework that conceptualizes adoption as a decision process involving information acquisition by farmers who vary in their risk preferences. This can be done by integrating the microeconomic foundations used to analyze production uncertainty at the farm level with the traditional technological adoption models. Specifically, Antle's (1987) approach which enables flexible estimation of the stochastic technology is used to evaluate individual risk preferences which then can be used to evaluate farmer's decision to adopt modern water saving technologies. The proposed model is applied to a randomly selected sample of 265 farms located in Crete, Greece.

The rest of the paper is organized as follows. Section 2 presents the theoretical framework used to analyze farmer's decision in the presence of production uncertainty. The data used in this study and the empirical model are discussed in Section 3 while the empirical results are analyzed in Section 4. Section 5 summarizes and concludes the paper.

2 Theoretical model

In this section, the representative agent production model under risk is developed. The farmer is assumed to be risk-averse and produces a single output q. Let p denote output price, $f(.)$ the production function assumed continuous and twice differentiable, X the vector of inputs, and r the corresponding vector of unit 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 $G(.)$ is exogenous to farmer's actions. This is the only source of risk we consider as prices p and r are assumed non-random 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 in the production function parameter $h(\alpha)$, where α represents 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:

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

where $U(.)$ 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:

$$E\left[r_w \times U'\right] = E\left[p\frac{\partial f\left(\varepsilon, h(\alpha)X_w, X_{-w}\right)}{\partial X_w} \times U'\right]$$

$$\Leftrightarrow \; \frac{r_w}{p} = E\left(\frac{\partial f\left(\varepsilon, h(\alpha)X_w, X_{-w}\right)}{\partial X_w}\right) + \frac{cov(U', \partial f\left(\varepsilon, h(\alpha)X_w, X_{-w}\right)/\partial X_w)}{E(U')}, \tag{2}$$

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), $cov(U', \partial f\,(\varepsilon, h(\alpha)X_w, X_-$ 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.

Proof: The Arrow-Pratt risk-premium $R(X)$ is defined as the amount of money that should be given to the risk-averse farmer for him to behave as a risk-neutral agent. A risk-neutral agent would maximize expected profit:

$$\max_X [p \times Ef\,(\varepsilon, h(\alpha)X_w, X_{-w}) - r'X - R(X)].$$

First order condition associated with water input defines the marginal risk premium with respect to water:

$$\frac{\partial R}{\partial X_w} = p \times E\left(\frac{\partial f\,(\varepsilon, h(\alpha)X_w, X_{-w})}{\partial X_w}\right) - r_w.$$

Rearranging the terms of (2):

$$p \times E\left(\frac{\partial f\,(\varepsilon, h(\alpha)X_w, X_{-w})}{\partial X_w}\right) - r_w = -\frac{p \times cov(U', \partial f\,(\varepsilon, h(\alpha)X_w, X_{-w})\,/\partial X_w)}{E(U')}.$$

Optimal water use X_w^* is the solution of equation (2). To derive an analytical solution to this equation, we would need to specify the farmer's preferences (its utility function $U(.)$), the production process ($f(.)$) and the distribution of the random variable representing risk ($G(.)$). To remain as general as possible, we simply write optimal water use as an unspecified function of input and output prices, technology, preferences and marginal risk-premium.

We now incorporate in our model the decision to adopt a new irrigation technology. This decision is modelled 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. 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:

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

and for the case of non-adoption:

$$\frac{r_w^0}{p} = E\left(\frac{\partial f\left(\varepsilon, h_0(\alpha)X_w^0, X_{-w}^1\right)}{\partial X_w}\right) + \frac{cov(U', \partial f\left(\varepsilon, h_0(\alpha)X_w^0, X_{-w}^1\right)/\partial X_w)}{E(U')}. \tag{4}$$

The farmer will adopt the new irrigation technology if the expected utility with adoption is greater than the expected utility before adoption. Expected utility under adoption is:

$$E\left[U(\Pi^1)\right] = \int \left[U(pf\left(\varepsilon, h_1(\alpha)X_w^1, X_{-w}^1\right) - r_w^1 X_w^1 - r'_{-w}X_{-w}^1 - I_1)\right] dG(\varepsilon), \tag{5}$$

and with no adoption:

$$E\left[U(\Pi^0)\right] = \int \left[U(pf\left(\varepsilon, h_0(\alpha)X_w^0, X_{-w}^0\right) - r_w^0 X_w^0 - r'_{-w}X_{-w}^0)\right] dG(\varepsilon). \tag{6}$$

The farmer will choose to adopt the innovate irrigation technology if:

$$E\left[U(\Pi^1)\right] - E\left[U(\Pi^0)\right] > 0. \tag{7}$$

Thus, the farmer's technology adoption choice depends on input and output prices, the fixed cost of the new technology, parameters of production technology, preferences and corresponding input-specific risk-premia, the distribution of risk and the farmer's characteristics. The empirical application of the above theoretical model follows a two-step procedure. First, it adopts Antle's (1983, 1987) approach, that allows estimation of the farmer's attitudes towards risk without specification of any of the above parameters that affect farmer's choice. Second, it incorporates the estimated risk attitudes in a traditional discrete choice econometric model that allows estimation of the parameters affecting the decision to adopt a technological innovation.

3 Empirical Application

3.1 Data Description

The dataset used in this study is extracted from a broader dataset, collected via a survey on the structural characteristics of the agricultural sector in Crete, financed by the Regional Directorate of Crete in the context of the Regional Development Program 1995-99 (Liodakis, 2000). The sample consists 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 adopted modern irrigation technologies during the year of the survey. Descriptive statistics are provided in Table 1.

Table 1. Descriptive Statistics.

Variable	Adopters	Non-Adopters
Economic Data:		
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 m3)	140	176
Total Cost (in Euros)	*36,189*	*45,198*
Total Revenue (in Euros)	*53,276*	*65,871*
Profits (in Euros)	*17,087*	*20,673*
Farm Characteristics:		
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
Index of Relative Risk Premium	0.460	0.522
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
No of Farms	87	178

Notes:

[1] One stremma equals 0.1 ha.

[2] Capital stock was estimated using the perpetual inventory method

[2] as described in Ball et al., (2001).

[3] Aridity index is defined as the ratio of the average annual temperature

[3] in the area over total annual precipitation.

In the sample of this survey, 87 out of 265 farms (32.8%) have adopted modern irrigation technologies. These technologies vary from simple sprinklers applied mainly in tree crops to greenhouse integrated systems that control the irrigation of the plantation.

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 m^3 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 and 11 years, 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 only 893 euros . Similarly the level of subsidies is also almost three times the level subsidies for innovative farms (1,194 and 444 euros, respectively). Although subsidies refer mainly to direct income transfers from CAP (common agiculture policy) and thus are not related with farmers' adoption process, it seems that it provides them 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 Empirical Model

As already indicated, the derivation of an analytical solution to (7) would require the specification of preferences through a utility function, technology and the distribution of (ε). To avoid too many ad hoc specifications, we adopt a two-stage procedure. In the first step, we assess risk attitudes using Antle's (1983, 1987) flexible estimation approach, that has the advantage of requiring only information on profit, price and input quantities. In the second step, we incorporate these risk attitudes among the explanatory variables of a probit econometric model, in order to explain the binary choice of whether to adopt or not a technological innovation.

They key feature of the flexible approach we use in the first step of our estimation procedure is that the farmer's maximization problem is equivalent to maximizing a function of moments of the distribution of profit (or equivalently, the distribution of ε), those moments having themselves X as arguments. There is no loss in generality here because these function of moments, denoted by $F(.)$, is completely unspecified. Moreover, the focus of our estimation procedure on a population of producers rather than on individual producers, avoids aggregation problems.

Under the assumptions that each farmer solves a single period maximization problem in which inputs are predetermined variables, all farmers have the same profit distribution and form the same expectations, the farmer's program becomes:

$$\max_X E\left[U(\Pi)\right] = F\left[\mu_1(X), \mu_2(X), \ldots, \mu_m(X)\right],$$

where μ_j, $j = 1, 2, \ldots, m$ is the j^{th} moment of profit. The first order condition of the program is approximated by the following Taylor expansion, in matrix form:

$$\frac{\partial\mu_1(X)}{\partial X} = -(1/2!)\frac{\partial\mu_2(X)}{\partial X} \times \frac{\partial F(X)/\partial\mu_2(X)}{\partial F(X)/\partial\mu_1(X)} - (1/3!)\frac{\partial\mu_3(X)}{\partial X} \times \frac{\partial F(X)/\partial\mu_3(X)}{\partial F(X)/\partial\mu_1(X)}$$

$$- \ldots - (1/m!)\frac{\partial\mu_m(X)}{\partial X} \times \frac{\partial F(X)/\partial\mu_m(X)}{\partial F(X)/\partial\mu_1(X)}.$$

We index by $k = 1, \ldots K$ inputs used in the production process and we assume that the farmer is concerned only by the first three moments of the distribution of profit. The marginal contribution of input k to the expected profit is given by $\partial\mu_1(X)/\partial X_k$, which is written as a linear combination of the marginal contributions of input k to the variance $(\partial\mu_2(X)/\partial X_k)$ and skewness $(\partial\mu_3(X)/\partial X_k)$ of expected profit. Hence the following model will be estimated for each input k:

$$\frac{\partial\mu_1(X)}{\partial X_k} = \theta_{1k} + \theta_{2k}\frac{\partial\mu_2(X)}{\partial X_k} + \theta_{3k}\frac{\partial\mu_3(X)}{\partial X_k} + u_k \tag{8}$$

where

$$\theta_{jk} = -(\partial F(X)/\partial\mu_j(X))/(\partial F(X)/\partial\mu_1(X)) \times (1/j!), \quad j = 1, \ldots, 3,$$

and u_k is the usual econometric error term. θ_{2k} and θ_{3k} are directly related to the theory of decision under risk, as $(2\theta_{2k})$ and $(-6\theta_{3k})$ are good approximations of Arrow-Pratt (AP) and down-side (DS) coefficients of risk-aversion, respectively. The risk-premium is then derived as follows:

$$RP_k = \mu_2\frac{AP_k}{2} - \mu_3\frac{DS_k}{6} \quad \text{for each } k \tag{9}$$

where μ_2 and μ_3 are respectively a measure of the second- and third-order moments of the distribution. $RP_k > 0$ would mean that the farmer is characteized by a positive willingnss to pay to be insured against the risk associated with the use of input k. Coefficients θ_{2k}

and θ_{3k} can aslo be interpreted as a measure of the marginal contribution of each of the two higher moments to the risk premium.

As indicated above, farm-specific relative risk premium for water input, is used in the second stage of our empirical model in order to proxy farm-specific risk attitudes. That is, this variable is then included in the discrete choice model that explains the probability of technology adoption as a function of risk attitudes, farmers' socio-economic characteristics and farm-specific qualitative and financial characteristics. Recall from section 2 that the farmer will choose to adopt the innovate irrigation technology if $Y_i^* \equiv E\left[U(\Pi_i^1)\right] - E\left[U(\Pi_i^0)\right] > 0$. 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:

$$Y_i^* \equiv \mathbf{Z}_i' \beta + e_i > 0 \tag{10}$$

where $\mathbf{Z}_i$ is a vector of regressors containing socio-economic (including risk attitudes) producer-specific characteristics, as well as quality, financial and information acquisition farm-specific characteristics, which determine the decision whether to adopt a new technology. β is a vector of parameters to be estimated and e_i is an error term. The binary choice is defined by assuming a popability density function (pdf) for e_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 distibution function (cdf) $F(\mathbf{Z}_i'\beta) = \int_{-\infty}^{\mathbf{Z}_i' \cdot \beta} \frac{1}{\sqrt{2\pi}} e^{-t^2/2} dt$.

3.3 Empirical Results

Table 2 reports the estimated risk parameters obtained from applying (8), to the data described in section 3.1, and calculating the relevant risk premium for water input using equation (9).

Table 2. Estimation of the risk-aversion measures.

Risk Parameter	Estimate	Std Error
Constant	-0.0267	0.0585
θ_{2k} (associated with AP)	0.9327	0.4446
θ_{3k} (associated with DS)	-0.9692	0.2049

Results confront to expectation and show that farmers are risk-averse. Firstly, the constant term is not significant, which indicates that irrigation water, the input under consideration is efficiently used, in the sense that expected marginal return is equal to the factor price.[1] The efficiency of the farmers allows application of Antle's method which assumes profit maximizing behaviour. Secondly, the θ_2 parameter associated with the second moment (variance) of profit is positive and significant, which indicates that farmers

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[1] This also indicates that the empirical model is correctly specified.

exhibit Arrow-Pratt risk aversion, i.e. they are willing to sacrifice a proportion of their expected profit in order to avoid the risk associated with water input in their production. Thirdly, the parameter linked to the third moment (skewness) of profit is negative and significant, which indicates that farmers also exhibit down-side risk aversion; i.e. they are risk averse to a profit distribution that is skewed towards negative values.

The flexible estimation of the stochastic production function allows us to calculate the relative risk that each farmer in the sample is willing to pay in order to avoid the risk associated with water used as an input in his/her production. This variable (the relative risk premium) is then used in the estimation of the choice model in order to investigate whether risk attitudes affect the decision to adopt a new irrigation technology. Table 3 reports the effects of all variables on the decision to adopt.[2] With the exception of the dummy variables indicating limestones soils (both clayey and marly) and location of farms in the region of Chania, all other variables included in the estimated probit model are significant at either 99% or 95% significance levels. In general, their signs conform to expectation and validate the theoretical model of section 2.

Table 3: Parameter estimates of the probit model.

Variable	Estimate	Standard Error
Constant	-4.6812	(1.9033)*
Farmer's Age	-0.0854	(0.0304)*
Farmer's Education	0.2045	(0.0847)*
Aridity Index	1.9626	(0.7472)*
Farm's Debts	0.0009	(0.0002)*
Extension Visits	0.0422	(0.0157)*
Access to Information	0.3110	(0.1043)*
Relative Risk Premium	0.1049	(0.0370)*
Subsidies	0.0038	(0.0008)*
Clayey Sandy	0.5558	(0.2787)**
Clayey Limestones	-0.1744	(0.3749)
Marly Limestones	-0.5553	(0.4550)
Chania	-1.1059	(0.4912)*
Rethymno	0.5242	(0.5119)
Lasithi	0.8681	(0.4340)**
% of Correct Prediction	97.84	
McFadden's R^2	94.40	

* (**) significant at the 1 (5)% level.

One useful expedient 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

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[2] In the probit model, the derivative of the probability with respect to the independent variables varies with the level of these variables. As a result, it is not generally useful to report the coefficients from a probit, unless only the sign and significance of the coefficients are of interest.

a "typical" element of the sample. These derivatives are reported in table 4 and represent the marginal effect of each regressor, which approximates the change in the probability of adoption at the regressors' mean. 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).

Table 4: Marginal effects on the probability of adoption.

Variable	Estimate	Standard Error
Farmer's Age	-0.02978	(0.0092)*
Farmer's Education	0.07128	(0.0234)*
Aridity Index	0.68394	(0.1546)*
Farm's Debts	0.00031	(0.0002)**
Subsidies	0.00132	(0.0003)*
Extension Visits	0.01471	(0.0033)*
Access to Information	0.10838	(0.0542)**
Relative Risk Premium	0.03656	(0.0102)*
Subsidies	0.00132	(0.0003)*
Clayey Sandy	0.19371	(0.0653)*
Clayey Limestones	-0.06077	(0.0843)
Marly Limestones	-0.19353	(0.1654)
Chania	-0.38541	(0.1342)**
Rethymno	0.18270	(0.2621)
Lasithi	0.30253	(0.1325)*

* (**) significant at the 1 (5)% level.

The variable of particular interest to this paper is the farmer-specific relative risk premium. This variable proxies the risk attitudes of each farmer in the sample and turns out to have a positive and significant effect on the decision to adopt new irrigation technologies. That is, farmers that are more risk-averse with respect to their use of water are more likely to adopt new technologies that allow 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.

As indicated in table 4, the older the farmer the less inclined he is to adopt new irrigation technologies, while the more educated his/she is the higher the probability that he/she adopts relevant technologies in their production. Moreover, as expected the more arid the location of the farm the higher the probability of adopting new water-saving irrigation technologies that help the farm face non-favorable environmental conditions.

In addition, financial variable seem to affect the probability to adopt. Farmers with higher debts as well as higher subsidies are more likely to adopt. As already indicated in the section 3.1, these subsidies refer mainly to direct income transfers implied by the respective common market organization of the CAP and thus are not related with farmers' adoption process. However, it seems that they provide the farmers with the financial viability necessary for investing in new technologies.

The exposition of the farmers to extension services (private or public) and their access to general farming information also increase the probability to adopt the new technology. That is farmers that adopt new technologies have better access to farming 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).

As far as soil dummies are concerned clayey sandy soils have a positive and significant effect on the decision to adopt. This can be explain by the fact that sandy soils require more water as they have high absorbing capacity than other types of soil, hence giving rise to incentives for water conservation through adoption of new technologies. The regional dummies for Chania and Lasithi are significant in explaining adoption technology. The difference in their signs indicates differences in cultivated crops between these two areas. In Lasithi green houses, which water intensive, are numerous and as a result respective farmers are more inclined to adopt a water-saving new technology. On the other hand, in Chania farmers mostly cultivate olive-trees with significantly lower water requirements and as a reduced incentives for investing in expensive water-saving irrigation technologies.

4 Conclusions

The main objective of this paper was to present a theoretical framework that conceptualizes adoption as a decision process involving information acquisition by farmers who face yield uncertainty and vary in their risk preferences. To do this we have constructed the relevant theoretical model by integrating the microeconomic foundations of decision making under production uncertainty at the farm level with the traditional technological adoption models.

The application of this theoretical model involves a two-step procedure. In the first step we apply Antle (1987) flexible method of moments, which enables estimation of the stochastic technology without ad hoc specification of risk preferences and derivation of input and farmer specific risk attitudes. In th second stage, these risk attitudes are incorporated in a discrete-choice model which explains farmer's decision to adopt irrigation technologies as a function of farmers' socio-economic characteristics, farm-specific financial and qualitative characteristics, as well as farmers' risk attitudes.

The proposed model is applied to a randomly selected sample of 265 farms located in Crete, Greece. Results show that risk preferences affect the probability of adoption and provide evidence that farmers invest in new technologies as a means to hedge against input related production risk. As a conclusion, this study shows that neglecting risk when assessing the choice of technology adoption could provide misleading guidance to policy makers. More precisely, we assess here that the second and third moments of the profit distribution influence farmer's decision to adopt a new technology and should be taken into account when policies that attempt to affect technology adoption are considered.

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