# Irrigation water management under risk: An application to Cyprus

Ben Groom

*Department of Economics/CSERGE, University College London*

Phoebe Koundouri

*Department of Economics, University of Reading and*
*Department of Economics/CSERGE, University College London*

Céline Nauges

*LEERNA-INRA, Toulouse*

Alban Thomas

*LEERNA-INRA, Toulouse*

*Abstract.*

We provide empirical evidence that attitude towards risk is important when assessing the impact of conservation policies on production choices. We first follow the approach used by Antle (1987) which enables flexible estimation of the stochastic technology without ad hoc specification of risk preferences. In a second step, the impact of water quotas on farmer decisions can be solved, using risk aversion and technology parameter estimates. Application is made on a farm-level data-set from the agricultural region of Kiti in Cyprus.

## Introduction

The last decade produced econometric evidence on the role of input-use adjustments as a response to higher water prices or reduced water entitlement. Recent studies established empirical evidence on the price elasticity of demand for irrigation water (Nieswiadomy, 1988; Ogg and Gollehon, 1989); quantified the effect of water price on irrigation development, irrigation technology choice, and irrigation technology demand (Caswell and Zilberman, 1985; Negri and Brooks, 1990; Nieswiadomy, 1988; Schaible et al., 1991); estimated the effect of reduced water entitlement on cropland allocation decisions (Moore and Negri, 1992) and used limited-dependent variable methods to estimate crop-choice, crop supply, land allocation, and water demand functions for field crops (Moore et al., 1994). The general conclusion of this literature is that producers adapt rationally to water-scarcity signals.

This research was also extended to non-deterministic environments, which allowed investigation of stochastic production responses (Fuller, 1965; Day, 1965 and Anderson, 1973). A relatively new aspect of stochastic production models is the estimation of the effect of input choice on risk. 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 in the variance of output. In this paper we investigate one such case, namely input conservation policies.

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.

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. This was Antle's departure point 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, 1980, 1982).

In the first section of the paper, we present the underlying model of farmer behaviour under risk and discuss implications of risk aversion for simple conservation policies (irrigation water quota). The difficulty in empirically specifying such model with respect to farmers' preferences, technology and distribution of risk, motivates the use of Antle's flexible moment-based approach. The data used for estimation, a microeconomic cross-section from the coastal agricultural area of Kiti (Cyprus), are described in Section 2. In the applied econometric analysis (Section 3), we derive crop-specific risk attitude characteristics (absolute Arrow-Pratt and down-side risk aversion coefficients and risk premium) and we analyse the impact of an irrigation water quota on input use and moments of profit. We show that neglecting risk when assessing impacts of conservation policies (irrigation water quota) on input choices and expected profit could provide misleading guidance to policy makers. The last section provides a summary of the main results derived in the paper.

## 1 Farmer behaviour under risk: input decisions and the quota

In this section we analyze the impact of an irrigation water quota on the production decisions of a farmer in a risky environment. Our focus here is on variable inputs in agricultural production, such as water, labour, fertiliser and pesticides, whose choice and mixture may be modified by the farmer in the short-run, in order to hedge against production risk. Consequently, land allocation decisions and their relationship with variable-input demand are not addressed here, as land is assumed a fixed factor.

In addition, fixed cost and technology choice considerations are outside the scope of this paper.[1] We assume throughout that technology is fixed and known to the environmental regulator. As for prices, we make the assumption that farmers are price-takers, so that a modification in their input allocation decision (following, e.g., the implementation of a conservation policy) will affect neither output, nor input prices. Finally prices are perfectly predictable in the short-run, so that they are considered non-random by the farmer.[2]

Assume the environmental agency selects a value for this quota in order to maximize a social welfare objective criterion that includes environmental considerations. Such a welfare function would typically include consumer surplus associated with the good produced, environmental externalities related to natural resource depletion, and so on. An important aspect of our framework is that the quota is exogenous, so that once it is chosen, farmers decide on their production plans considering this quota as given. Both problems (choice of quota conservation policy and decision on the production level) are thus completely separated. This is because the agency's environmental criterion is based upon the whole population of farmers through some technological and preference representation, whereas each farmer is too small to influence the agency's decision.

A key ingredient to assess accurately the performance of such a conservation policy is naturally the sensitivity of producers to different values of the quota (the conservation policy instrument). This requires first, an adequate representation of the technology, but also of farmer preferences towards risk. It is well known that ignoring possible distortions in production decisions due to risk aversion can lead to misleading results (Just and Pope, 1978; Aigner et al., 1977; Griffiths and Anderson, 1982). When production risk originating from, e.g., extreme climatic conditions, is likely to be significant, farmers are often hedging against such risk by modifying input choices. For example, when a drought is likely to affect crop yield, extra use of irrigation water appears to be a natural way to limit plant water stress.

## 1.1 The production model

In this section, the basic representative agent production model under risk is developed. As noted above, we assume an exogenously-given quota whose determination is not detailed here.

Let $p$ denote output price for a single crop, $f(.)$ is the production function, $X$ is the $K$ vector of inputs, and $r$ is the corresponding vector of unit input prices. The environmental policy quota is directed towards a single input, irrigation water in our case, which is denoted $X_w$ with associated unit price $r_w$. We then have $X' = (X_1, X_2, \ldots, X_{K-1}, X_w)$ and $r' = (r_1, r_2, \ldots, r_{K-1}, r_w)$. The restriction imposed on $X_w$ is written

$$X_w \leq \bar{X}_w, \tag{1}$$

where $\bar{X}_w$ is either a quota in absolute terms, or in relative terms. In the latter case, we would have for example $\bar{X}_w = (1 - \delta)X_w^0$, with $X_w^0$ the reference water consumption, and $\delta$ the desired rate of reduction in water use. We assume that there exists a single source of risk affecting crop yield, denoted $\varepsilon$, whose distribution $G(.)$ is not affected by farmer actions (exogenous climatic conditions, etc.). In addition, we assume prices $p$ and $r$ to be non random, so that the only source of risk is production risk through the random variable $\varepsilon$. Let us suppose further that $f(.)$ is continuous and twice differentiable. The agent problem is to maximize expected profit if she is risk-neutral, or to maximize the expected utility of profit if she is risk-averse, subject to condition (1). In the latter case, the agent's problem is

$$\max_X E\left[U(\Pi)\right] = \max_X \int \left[U(pf(\varepsilon, X) - r'X)\right] dG(\varepsilon) + \lambda(\bar{X}_w - X_w), \tag{2}$$

where $U(.)$ is the Von Neuman-Morgenstern utility function and $\lambda$ is the Lagrange multiplier associated with (1). The optimal solution for action $X$ would then depend upon $(p, r)$ and on the shape of functions $U(.)$, $f(.)$ and $G(.)$. The first-order condition associated with this problem is for irrigation water input $X_w$:

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

$$\Leftrightarrow \frac{r_w + \lambda/E(U')}{p} = E\left(\frac{\partial f(\varepsilon, X)}{\partial X_w}\right) + \frac{Cov(U', \partial f(\varepsilon, X)/\partial X_w)}{E(U')}, \tag{3}$$

because $p$ and $r_w$ are not random, and where $U' = \partial U(\Pi)/\partial \Pi$. It is apparent that the shape of the utility function (whose curvature is increasing with the degree of absolute risk aversion) will determine the magnitude of the departure from the risk-neutrality case. For a risk-neutral producer, the price ratio under the quota policy, $(1/p)[r_w + \lambda/E(U')]$ equals the expected marginal productivity of $X_w$. When the producer is risk-averse, the second term in the right-hand side of (3) is different from 0, 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 $X_w$. If the latter is risk increasing, the marginal risk premium increases with $X_w$ and the desired level of that input decreases, all other things being equal.

In principle, solving Equation (3) for $X_w$ yields the equilibrium input quantity in terms of $p$, $r$, $\bar{X}_w$ and $\lambda$. However, the problem is empirically difficult. In addition to the choice of technology specification, the distribution of $\varepsilon$ needs to be known and preferences specified through the utility function. We thus choose a flexible approach that has the advantage of requiring only information on profit, price and input quantities. The key feature of this approach is to note that the solution to the producer problem can be written as a function of input levels alone. More precisely, maximizing the expected utility of profit under the quota restriction with respect to any input, is equivalent to maximizing a function of moments of the distribution of profit (or equivalently, the distribution of $\varepsilon$), those moments having themselves $X$ as an argument. There is no loss of generality here, because such a function of the moments, denoted $F(.)$, is completely unspecified. The farmer's program becomes:

$$\max_X E\left[U(\Pi)\right] = F\left[\mu_1(X), \mu_2(X), \ldots, \mu_m(X)\right] \text{ subject to } X_w \leq \bar{X}_w,$$

where $\mu_j$, $j = 1, 2, \ldots, m$ is the $m^{th}$ moment of profit.

### 1.2 Assessing risk attitudes: Antle's approach

Based on the expression above, Antle (1983, 1987) proposes a moment-based approach to estimate risk-attitude parameters of a population of producers. Focusing on the population instead of focusing on each individual producer has two main advantages. It avoids any problem of aggregation of individuals and allows the identification of the risk-attitude parameters from a cross-sectional data set. However, this approach relies on some assumptions. First, the farmer solves a single-period maximisation program in which inputs are predetermined variables. Second, all farmers produce with similar technology. Below, this stochastic technology is represented by the corresponding distribution of profit, which amounts to assuming that the same profit distribution applies to each farm and that all farmers form the same expectations. We now describe more precisely Antle's method, without considering for now any constraint on input use.

The first order condition can be approximated by the following Taylor expansion, in matrix form:

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

We index as before by $k = 1, \dots K$ the inputs used in the production process and we denote by $\alpha_{jk}$ the expression $\big(\partial F(X)/\partial \mu_j(X)\big)/\big(\partial F(X)/\partial \mu_1(X)\big)$. $\alpha_{jk}$, $(j = 2, \dots, m)$ represents the $j^{th}$ average population risk attitude parameter related to input $k$. For each input $k$, we will thus have $(m-1)$ unknown parameters. Each of the $K$ equations described below will be estimated separately.

$$\frac{\partial \mu_1(X)}{\partial X_k} = -\alpha_{2k} \times (1/2!)\frac{\partial \mu_2(X)}{\partial X_k} - \alpha_{3k} \times (1/3!)\frac{\partial \mu_3(X)}{\partial X_k} - \cdots - \alpha_{mk} \times (1/m!)\frac{\partial \mu_m(X)}{\partial X_k}.$$

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 other moments (variance: $\partial \mu_2(X)/\partial X_k$, skewness: $\partial \mu_3(X)/\partial X_k$, ...). $\alpha_{mk}$ measures the "weight" attributed by the farmer to the $m^{th}$ moment of his profit distribution. The analysis is made input by input because each input contributes in a different manner to the moments of the profit distribution. In general, we expect that all inputs increase the expected profit but, for the second-order moment, we can find risk-increasing as well as risk-decreasing inputs.

The following model will be estimated for each input $k$:

$$\frac{\partial \mu_1(X)}{\partial X_k} = \theta_{1k} + \theta_{2k}\frac{\partial \mu_2(X)}{\partial X_k} + \theta_{3k}\frac{\partial \mu_3(X)}{\partial X_k} + \cdots + \theta_{mk}\frac{\partial \mu_m(X)}{\partial X_k} + u_k \qquad (4)$$

where

$$\theta_{2k} = -\alpha_{2k} \times (1/2!), \quad \theta_{3k} = -\alpha_{3k} \times (1/3!), \quad \dots, \quad \theta_{mk} = -\alpha_{mk} \times (1/m!)$$

and $u_k$ is the usual econometric error term. A nice feature of this model is that the parameters $\theta_{2k}$ and $\theta_{3k}$ are directly related to the theory of decision under risk and thus can give insights to the nature of farmer's risk preferences. More precisely, $\theta_{2k}$ and $\theta_{3k}$ are directly interpretable as Arrow-Pratt and down-side risk aversion coefficients respectively: Arrow-Pratt (AP) absolute risk aversion coefficient is defined by:

$$AP_k = -\frac{E(U''(\Pi))}{E(U'(\Pi))} \simeq -\frac{\partial F(X)/\partial \mu_2(X)}{\partial F(X)/\partial \mu_1(X)} = 2\theta_{2k}.$$

A positive AP coefficient means that the farmer is risk-averse. Down-side (DS) risk aversion is measured by:

$$DS_k = \frac{E(U'''(\Pi))}{E(U'(\Pi))} \simeq \frac{\partial F(X)/\partial \mu_3(X)}{\partial F(X)/\partial \mu_1(X)} = -6\theta_{3k}.$$

A positive DS coefficient means that the farmer is averse to down-side risk.[3]

AP and DS coefficients can then be used to compute the risk premium RP. Assuming that the farmer is concerned by the first three moments of the distribution only, we have

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

where $\mu_2$ and $\mu_3$ are respectively a measure of the second- and third-order moments of the distribution. $RP_k > 0$ would mean that the farmer is characterized by a positive willingness to pay to be insured against the risk associated with the use of input $k$. Coefficients $\alpha_{2k}$ and $\alpha_{3k}$, directly related to $AP_k$ and $DS_k$, can also be interpreted as a measure of the marginal contribution of each moment to the risk premium.

## 2 Data set description

Cyprus is representative of arid and semi-arid regions in general, typified by low and variable rainfall and overuse of groundwater resources. Irrigation based agriculture plays an important role in the country's economy. Agriculture contributes 6% of GDP, 25% to merchandise exports, an additional 11% coming from processed agricultural goods, while 10% of employment is in agriculture. There is a wide variety of crops grown in Cyprus ranging from the permanent crops such as olives, citrus and other deciduous fruits and nuts, to more temporary cereal and vegetable crops. In Cyprus as a whole 75% of all annual water use is in the irrigation sector. This is equivalent to approximately 160 millions cubic meters per year from a total of 210.

The farm level data is drawn from a survey of agricultural production of the coastal Kiti region of Cyprus undertaken by the University of Cyprus and the Ministry of Agriculture in the summer of 1998. The Kiti region lies within the southerly Larnaca area of Government controlled Cyprus. To date over 2200 ha of irrigation has been developed in the Larnaca area (MIT, 1999) and historically the Kiti region has been dependent upon groundwater to sustain irrigated agriculture. The Kiti-Larnaca coastal aquifer is understood to have a sustainable yield of approximately 2 millions cubic meters per year. Although it is difficult to obtain precise data on the balance of replenishment and abstraction, the well-documented salinization of groundwater in the Kiti region suggests that salt water intrusion is occurring as a result of over-pumping (e.g. Koundouri, 2000).

The data set consists of a cross-section of 283 farmers and provides accurate information regarding production activities on representative parcels of their land. In particular, expenditures upon, and quantities of, fixed and variable inputs used in production (land, pesticides, fertiliser, labour and water) and crop output levels are available. The total area of land owned by the farmer and the area(s) devoted to irrigated/non-irrigated and temporary/permanent crops are also provided, as well as information on farm ownership, family characteristics and access to water resources. Table 1 lists the crops grown by the farmers in the surveyed cross-section and shows the areas of land devoted to the respective crops. The total area of land cultivated by the farmers is 807 ha of which approximately 42% is irrigated.

**Table 1 here**

The cross-section sample represents approximately 15% of the developed irrigated land in the Larnaca area. A comparison to national statistics (see Agricultural Research Institute, 1998) reveals that the Kiti region provides a reasonable representation of the composition of crop production in Cyprus as a whole. The wide variety of crop types represented in the sample necessitated the grouping of crops into broad categories to overcome the sparseness of individual crop observations. Crops have been grouped into three categories as shown in Table 1, namely: vegetables, citrus and cereals.

Data on the quantities of water used in crop production were sparse and often inconsistent. In response, information regarding water requirements for the specified crops were gathered from the Ministry of Agriculture (Agricultural Research Institute, 1998) and were used to calculate theoretical water demands for the farms based on the areas of land devoted to particular crops. This information is used when farm specific data on irrigation water is missing. Water requirements for respective crops are shown in Appendix A1. These estimates are taken from the Agricultural Research Institute (1998).

Although one of the questions in the questionnaire concerned water use and water costs, the responses for these particular questions were sparse and did not reveal the marginal costs faced by individual farmers. In response to this we have constructed a tariff for groundwater pumping costs based on hydrological information obtained from the Ministry of Agriculture in Nicosia (see Appendix A2). It is apparent that some of the farms use water from other sources; perhaps piped water from the government, water vendors (tankers) and local surface water schemes. Data is available regarding the price of these sources, however it is difficult to determine the proportions in which these sources are used. It is assumed here that farms are totally reliant on groundwater.

The descriptive statistics presented in Table 2 reveal that the Kiti region provides a reasonable representation of the composition of crop production in Cyprus as a whole.

**Table 2 here**

The data sample used is almost equally dominated by agricultural parcels which cultivate vegetables (135 parcels) and cereals (130 parcels). Relatively few agricultural units choose to cultivate citrus (30 parcels). Moreover, on average more hectares per parcel of land are devoted to vegetables (2.87) and cereals (2.79) cultivation, rather than citrus cultivation. While mean annual crop-specific gross revenues (total sales) per hectare of land are higher for vegetables and citrus, citrus cultivation involves higher mean input expenditure if compared with input costs for vegetable and cereals cultivation. It is worth noting however that input-specific expenditure variability is higher for citrus only with regards to labour inputs if compared to variability in input expenditure specific to vegetable and cereals production. Annual mean water expenditure is higher for citrus while annual variability in water expenditure is higher for vegetables.

# 3 Econometric estimation and results

## 3.1 Measurement of risk-attitude parameters

Following Antle (1987), we propose to estimate the sample-average risk-attitude parameters. As before, we distinguish between three groups of producers (producers of vegetables, citrus and cereals) and four inputs: fertiliser (including manure), pesticides, labour and water.[4] We wish not to impose a priori the equality of risk-attitude parameters between the four different inputs. However, we need to impose this equality constraint on the parameters in the citrus group because of too few observations. For each of the three groups, our estimation methodology is the following: first, we estimate the conditional expectation of profit using a quadratic functional form: total observed profit is regressed on all levels, squared and cross-products of input expenditures.[5] The residuals of the latter regression are then used to compute conditional higher moments (variance and skewness) and are regressed on all levels, squared and cross-products of input expenditures. We restrict ourselves to the third moment of profit for the following reasons. First, higher-order moments (kurtosis, etc.) are likely to exhibit collinearity with those moments already exploited. Second, and perhaps more important, risk attitude parameters $AP$ and $DS$ depend only on the first, second and third moments of profit. Moreover, it seems difficult to draw meaningful economic interpretations from moments higher than order three.

Analytical expressions for derivatives of these moments with respect to each input are then computed. We finally fit a 2SLS equation of the estimated derivative of the expected profit on derivatives for higher moments, for each input.[6] The parameters associated with the second and third moment will respectively be denoted by $\theta_{2k}$ and $\theta_{3k}$ for each input $k$. Estimated parameters are then used to recover Arrow-Pratt (AP) and down-side (DS) risk aversion measures using the following relationships:

$$AP_k \simeq 2\hat{\theta}_{2k} \quad \text{and} \quad DS_k \simeq -6\hat{\theta}_{3k}, \;\; k = 1, \ldots, K.$$

These estimates are finally used to compute the average risk premium $\rho_k$ as a proportion of expected net returns for each input $k$, which is approximately equal to

$$\frac{\rho_k}{\mu_1} = \frac{\mu_2 AP_k}{2\mu_1} - \frac{\mu_3 DS_k}{6\mu_1}$$

where $\mu_2$ and $\mu_3$ are the sample second- and third-order moments of the profit distribution respectively.

Estimation results for the sub-group of vegetable producers are found in Table 3.

**Table 3 here**

The Wald test rejects the null of equal parameters between all four inputs. In all four models, the parameters $\theta_2$ associated with the second moment (variance of profit) are positive and significant whereas the parameter linked to the third moment is significant for only two inputs (water and labour). Signs of these coefficients are "as expected" for all four inputs, showing risk-aversion of vegetable producers (through both the Arrow-Pratt and down-side risk measures). In the estimation process, the relative risk premium is not constrained to be positive. However, when computing the sample average of the relative risk premium, we exclude observations not consistent with the assumption of risk-neutrality or risk aversion, for which the risk-premium is negative. The average relative risk-premium is similar across inputs, ranging from 17% (for fertiliser and pesticides) to 20% (for labour) of expected profit.

Results for the sub-group of citrus producers are reported in Table 4.

**Table 4 here**

The small number of observations prevents the estimation of separate models for the four inputs. If the measures of Arrow-Pratt and down-side risk aversion are also positive in this group, the magnitude is larger than in the vegetables group. The average risk-premium is found to be 9% of the expected profit.

Results for the cereals sub-group are reported in Table 5.

**Table 5 here**

The Wald test rejects the null of parameter equality between inputs. The parameter linked to the variance is positive and significant in all models except for fertiliser. Thus, we get positive Arrow-Pratt risk aversion measures for all inputs except fertiliser.[7] The down-side measure has an unexpected negative sign for pesticides and labour but is insignificant. The down-side risk measure is positive and significant for the case of water only. The relative risk premia are lower in the cereals group compared to the group of vegetables producers (it ranges in this case from 6 to 15%). In particular, the figures obtained for water are different in the two groups. The risk premium represents 7% of the profit in the cereals group whereas we find a number equal to 19% in the vegetables group.

Note finally that the constant term is significant in some models, indicating that the Taylor series approximation to the first-order condition from the profit maximisation problem may be poor. This problem was recognised by Antle, and several explanations have been suggested (Antle 1987) for this problem.

### 3.2 Simulation of water quotas

We present in this section a simulation experiment where the irrigation water quota is assumed exogenous, and the farmer reacts to this artificial conservation policy by reallocating her production inputs. The way the environmental agency views farmers' preferences may be crucial in practice for policy design as well as for analysing expected policy results. We therefore consider two different simulation scenarios. In scenario 1, the agency is assumed fully informed of the farmers' attitudes towards risk, and expected policy outcomes account for this, in particular concerning the risk premium. For this scenario, the three moments of profit distribution are explicitly integrated in the policy simulation model. In scenario 2 on the other hand, the regulator is assumed to take decisions and interpret policy results based on farmers' expected profit only, i.e., under the assumption of risk neutrality. This seems to be the most usual way to handle conservation policies in practice (see Fraser, 1986, 1995) and the objective of this section is to investigate whether such "naive" behaviour for the regulator induces significant differences from the risk-aversion case.

From the discussion in Section 1, the system of first-order conditions derived from farmer's program under scenario 1 is

$$\begin{cases} \frac{\partial \mu_1(X)}{\partial X_1} & = & \theta_{21}\frac{\partial \mu_2(X)}{\partial X_1} + \theta_{31}\frac{\partial \mu_3(X)}{\partial X_1} \\ \vdots & = & \vdots \\ \frac{\partial \mu_1(X)}{\partial X_{K-1}} & = & \theta_{2,K-1}\frac{\partial \mu_2(X)}{\partial X_{K-1}} + \theta_{3,K-1}\frac{\partial \mu_3(X)}{\partial X_{K-1}} \\ \frac{\partial \mu_1(X)}{\partial X_w} & = & \theta_{2w}\frac{\partial \mu_2(X)}{\partial X_w} + \theta_{3w}\frac{\partial \mu_3(X)}{\partial X_w} + \lambda \\ 0 & = & \lambda(\bar{X}_w - X_w) \end{cases}$$

where $\lambda$ is the multiplier associated to the constraint on water use. In scenario 2, the second and third moments of the distribution are simply forgotten. The system is thus very simple with each equation setting the derivative of the expected profit to zero. When estimating the system in both scenarios, we test for significance of the constant term in each equation.

In scenario 1, we replace the $\theta$ parameters by their estimates, obtained in the previous section, and solve the system in $X_k$ $(k = 1, \ldots, K)$. Given that the moment functions $\mu_j(X), j = 1, 2, 3$ are quadratic, the system above contains only linear combinations of input levels, and a direct solution is easily obtainable.

One input has to be fixed for the system to be solvable. We assume that land is a fixed input in the short run. Moreover, given that output and input prices are assumed constant, it is not realistic to draw inferences from a simulation scenario that results in input values very far from reference values. This is because we consider only adjustments through input quantities other than land. Presumably, if the quota policy requires large variations in water use from the reference case, farmers are likely to react, not only by adjusting the levels of their other inputs, but also by reallocating crop land, possibly also modifying prices.

We solve the system for vegetables and cereals separately, at their sample mean.[8] We simulate a proportional quota and report the results for a quota corresponding to a 10% reduction of water use.[9] The impacts of the quota are measured in terms of their effect on use of other inputs and expected profit in both scenarios. We also incorporate the impact of the quota on variance and skewness of profit and absolute risk-premium (RP) for scenario 1. The figures reported in Table 6 are the variations in percentage from the reference case (without quota).

**Table 6 here**

The impacts on inputs in scenario 1 are as follows. In the vegetables group, the 10% reduction in water use leads to an increase in labour expenditures (+1.3%) and a decrease in fertiliser (-3.4%) and pesticides (-0.4%). The signs of the variations indicate that fertiliser and pesticides are complements to water whereas labour is a substitute. The expected profit increases by 3.5%. The quota also leads to a greater variance and lower skewness of the profit distribution (we know that risk-averse farmers are willing to pay to avoid a large variance and a small skewness). In the present case, the impact on the variance is larger than the impact on skewness which means that, overall, the quota on water increases the risk associated with the growing of vegetables. In this respect, water can be described as a risk-decreasing input for the vegetable production. The overall effect is an increase in the absolute risk premium (+ 2.7%). The increase in expected profit could be surprising at first sight.

In the cereals group, the impacts on moments of profit implied by the quota are much smaller than the ones observed in the vegetables group. This is not really surprising knowing that the production of vegetables is much more dependent on water than the production of cereals (73 farmers over 129 grow cereals on dry lands). We note in this group a complementarity between water and labour and between water and pesticides and a substituability between water and fertiliser. The average expected profit decreases by 3.2%, given by the increase in the variance. The risk-premium is almost unchanged in this group (change of -0.44%).

Coming now to scenario 2, we note that both the reallocation of inputs following the quota and the change in expected profit (sign and magnitude) are different between the two scenarios. If vegetable growers are found to increase the utilisation of labour and decrease the use of pesticides whatever their attitude towards risk is, the impact on fertiliser is not the same in the two scenarios. The producers of vegetables decrease the amount of fertiliser under scenario 1 whether they are increasing the use of its input when risk-neutrality is assumed. This could mean that fertiliser is a risk-increasing input in vegetables production. The findings are more striking when we compare change in expected profit. Assuming that growers of vegetables are risk-neutral would lead us to conclude that the quota would make them lose 1.26% of their current expected profit. However if risk-aversion is considered, these farmers are found to receive extra profit from the quota (+3.47%) combined however, with an increased risk premium.

In the cereals group, we still note quite surprising results concerning fertiliser (see estimation of risk-aversion parameters), in particular when risk-neutrality is assumed (fertiliser expenses are found to increase by 42%). The impact on the other inputs is quite small. We find in both cases that labour is a complement to water. Risk-neutral growers would increase the use of pesticides whereas they would decrease it under a risk-averse environment. Both scenarios lead to a negative change in expected profit, the magnitude of the change being greater under the risk-aversion assumption.

The significant differences between the two scenarios come from the fact that under risk-neutrality reallocation of inputs is only determined by technological constraints, whereas under risk-aversion farmers reallocate inputs by considering not only technological issues but also risk hedging.

## Conclusion and suggestions for further research

In this paper we have developed a method to analyse the impact of an irrigation water quota on input use and moments of profits for farmers facing risk. First, Antle's flexible moment-based approach is used to estimate risk-attitude parameters and extended then to simulate the impact of water conservation policies. We distinguish three sub-groups of producers: vegetable, citrus and cereal producers. Risk-attitude parameters are estimated assuming they are input-specific. We show that Cypriot farmers in the Kiti area exhibit absolute Arrow-Pratt and down-side risk aversion in most cases. The relative risk-premium has been derived and, for the case of irrigation water, it appears to be greater for the producers of vegetables (19% of profit) than for the producers of cereals (7% of profit). The greater dependency on irrigation water of vegetable growers is also emphasized through the results of quota simulation. The 10% quota is found to have a larger impact on this group leading to an increase in the risk-premium. As a conclusion, this study shows that neglecting risk when assessing impacts of conservation policies (irrigation water quota) on input choices and expected profit 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 behaviour and should be taken into account when policy evaluations are made.

This result also has important implications for agricultural policy, given the current debate on the linkage between environmental and agricultural objectives. The impact of a conservation policy (such as the one presented in this paper) on agricultural revenue should not only be assessed in terms of (foregone) expected profit from production alone. This impact should also include the change in revenue as the consequence of hedging against a modified production risk. This variation in revenue would originate from the need for the farmer to modify the insurance behaviour, which is reflected by the change in his risk premium. Therefore, in the case where agricultural policy should include environmental objectives, agricultural subsidy schemes should be designed simultaneously with the environmental planner, while accounting for risk considerations, as noted above.

Dynamic positive equilibrium programming (Gohin, 2000) is another economic tool for applied production analysis, which offers a methodology for dealing with time series about economic agents' decisions, regardless of the amount of available information. Like the estimation methods used in this paper, it allows estimation from a single cross-section and it avoids aggregation problems. Extending this method to accommodate estimation of risk attitudes could offer an alternative to Antle's methodology and an interesting source of comparison of respective derived results.

# Appendix

## Appendix A1

**Table A1 here**

## Appendix A2. Pumping Costs

The average depth from the surface of groundwater is known for particular areas of the Kiti region, and we have geographical data for the farms; they are located in one of six zones in the Kiti Region. In combination with knowledge of the marginal pumping cost for given lifts of groundwater and the theoretical or stated quantity of water used we are able to construct water expenditure data for each farm. The area-specific hydrological data on pumping lifts are incorporated in the following equation representing the marginal cost of groundwater pumping:

$$c(h(t)) = k_1[h(t)]$$

where $h(t)$ measures the pumping lift, i.e., the height through which groundwater must be pumped to arrive at the surface, and $k_1 = 0.02$ CYP/m$^3$ (Koundouri 2000). Given that we have six zones we end up with six groundwater marginal costs, as described in Table A2.

**Table A2 here**

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## Footnotes

1. See Green et al. (1996) for an analysis of irrigation technology choice.
2. This assumption is not critical as long as farmers are price-takers. Extending the model by allowing for price risk in addition to production risk, although feasible, would not bring about significant changes in the analysis.
3. Down-side risk is concerned with asymmetric (skewed) statistical distributions of profit.
4. We do not measure risk-attitude parameters associated with the use of land, as this input is assumed fixed in the short run.
5. All variables are rescaled by their standard deviation.
6. Instruments are total rainfall in 1998, soil quality and total present value of investment in machinery.
7. The magnitude and signs of both risk-aversion measures are counterintuitive and we will have to remain cautious when interpreting the role of fertiliser in cereals production.
8. We do not simulate the quota in the citrus group due to the insufficient number of observations.
9. As variations in input use are proportional to the quota (in percentage terms) in our case, we only consider a single case for the proportional quota.

Table 1: Crop Areas in the Kiti Region of Cyprus

| Crop group | Crops | Irrigated area (ha) | Dry land area (ha) | Total area (ha) | % of total area |
|---|---|---|---|---|---|
| **VEGETABLES** | okra | 8.3 | 0.0 | 8.3 | 1.0% |
| | tomato | 6.7 | 0.0 | 6.7 | 0.8% |
| | green beans | 0.5 | 62.9 | 63.4 | 7.9% |
| | watermelon | 11.0 | 0.0 | 11.0 | 1.4% |
| | melon | 8.4 | 0.0 | 8.4 | 1.0% |
| | marrow | 2.0 | 0.0 | 2.0 | 0.2% |
| | egg-plants | 3.1 | 0.0 | 3.1 | 0.4% |
| | peppers | 0.2 | 0.0 | 0.2 | 0.0% |
| | cucumber | 2.7 | 0.0 | 2.7 | 0.3% |
| | cabbage | 1.5 | 0.0 | 1.5 | 0.2% |
| | artichokes | 22.6 | 0.0 | 22.6 | 2.8% |
| | onions | 2.8 | 0.0 | 2.8 | 0.3% |
| | black eye beans | 1.3 | 0.0 | 1.3 | 0.2% |
| | lettuces | 2.2 | 0.0 | 2.2 | 0.3% |
| | cauliflower | 1.3 | 0.0 | 1.3 | 0.2% |
| | celery | 1.2 | 0.0 | 1.2 | 0.1% |
| | parsley | 0.07 | 0.0 | 0.07 | 0.00% |
| | corriander | 56.1 | 53.2 | 109.3 | 13.5% |
| | broad beans | 33.2 | 100.1 | 133.3 | 16.5% |
| | olives | 7.8 | 0.0 | 7.8 | 1.0% |
| | **Total** | **173** | **216** | **389** | **48.2%** |
| **CITRUS** | lemons | 25.0 | 0.0 | 25.0 | 3.1% |
| | oranges | 9.0 | 0.0 | 9.0 | 1.1% |
| | grapefruits | 13.2 | 0.0 | 13.2 | 1.6% |
| | mandarin | 0.5 | 0.0 | 0.5 | 0.1% |
| | **Total** | **48** | **0** | **48** | **5.9%** |
| **CEREALS** | bran | 0.8 | 52.5 | 53.3 | 6.6% |
| | barley | 45.4 | 107.3 | 152.7 | 18.9% |
| | wheat | 58.5 | 59.3 | 117.8 | 14.6% |
| | corn | 16.1 | 29.9 | 46.0 | 5.7% |
| | **Total** | **121** | **249** | **370** | **45.8%** |
| **Grand Total** | | **342** | **465** | **807** | **100%** |

Table 2: Descriptive statistics by group of crops

| | VEGETABLES | | CITRUS | | CEREALS | |
|---|---|---|---|---|---|---|
| | Mean | Std Dev. | Mean | Std Dev. | Mean | Std Dev. |
| Surface allocated (A)[1] (ha) | 2.87 | 5.79 | 1.59 | 2.12 | 2.79 | 4.11 |
| Net revenue/Ha (CYP/a)[2] | 2614.91 | 4079.79 | 2268.53 | 1572.31 | 628.33 | 1138.26 |
| Fertiliser (F)[3] expend. (CYP/ha/a) | 201.53 | 395.50 | 102.99 | 125.35 | 85.43 | 274.56 |
| Pesticides (P) expend. (CYP/ha/a) | 156.98 | 450.77 | 124.42 | 127.12 | 39.24 | 127.74 |
| Labour (L)[4] expend. (CYP/ha/a) | 498.79 | 1554.44 | 1219.23 | 3885.66 | 113.93 | 235.77 |
| Water (W) expend. (CYP/ha/a) | 359.66 | 359.00 | 940.57 | 140.82 | 104.23 | 211.34 |
| number of observations | 135 | | 30 | | 130 | |

[1]: includes irrigated and not irrigated area.

[2]: CYP: Cyprus pound (1 CYP is around 1.5 US Dollar.)

[3]: including manure.

[4]: casual work in crop production.

Table 3: Estimation of the risk-aversion measures - vegetables group

| | Fert | | Pest | | Water | | Labour | |
|---|---|---|---|---|---|---|---|---|
| | Est | Std Error | Est | Std Error | Est | Std Error | Est | Std Error |
| constant | -0.0245 | 0.0715 | 0.1169 | 0.0729 | 0.4750 | 0.0953 | 0.0872 | 0.0341 |
| $\theta_{2k}$ | 1.2726 | 0.4159 | 2.1143 | 0.2139 | 2.6204 | 0.6492 | 3.3474 | 0.4803 |
| $\theta_{3k}$ | -0.5222 | 0.6936 | -0.6346 | 0.8011 | -1.4290 | 0.3464 | -0.6503 | 0.1985 |
| $AP$ | 2.55 | 0.83 | 4.23 | 0.43 | 5.24 | 1.30 | 6.69 | 0.96 |
| $DS$ | 3.13 | 4.16 | 3.81 | 4.81 | 8.57 | 2.08 | 3.90 | 1.19 |
| RP | 17% | | 17% | | 19% | | 20% | |

Total number of observations: 134.

Wald test of parameters equality: 1771.0 (p-value: 0.0000).

Table 4: Risk-aversion measures
Citrus group

| | Est | Std Error |
|---|---|---|
| constant | 0.1432 | 0.0222 |
| $\theta_2$ | 7.8820 | 0.7078 |
| $\theta_3$ | -20.7043 | 2.0907 |
| $AP$ | 15.76 | 1.42 |
| $DS$ | 124.23 | 12.54 |
| RP | 9% | |

Total number of observations: 30.

Table 5: Estimation of the risk-aversion measures - cereals group

| | Fert | | Pest | | Water | | Labour | |
|---|---|---|---|---|---|---|---|---|
| | Est | Std Error | Est | Std Error | Est | Std Error | Est | Std Error |
| constant | 1.8323 | 2.2060 | -0.3296 | 0.1863 | 0.1433 | 0.0400 | -0.1239 | 0.0739 |
| $\theta_{2k}$ | -6.2677 | 31.6160 | 3.0259 | 0.3879 | 0.8595 | 0.1672 | 1.4512 | 1.8517 |
| $\theta_{3k}$ | -11.6667 | 47.1635 | 4.4149 | 3.4636 | -1.4992 | 0.4680 | 4.8560 | 4.3717 |
| $AP$ | -12.54 | 63.23 | 6.05 | 0.78 | 1.72 | 0.33 | 2.90 | 3.70 |
| $DS$ | 70.00 | 282.98 | -26.49 | 20.78 | 9.00 | 2.81 | -29.14 | 26.23 |
| RP | - | | 15% | | 7% | | 6% | |

Total number of observations: 129.

Wald test of parameters equality: 1570.3 (p-value: 0.0000).

Table 6: Expected impacts (in %) a proportional 10% water quota, for different scenarios

| Crop | Fert | Water | Labour | Pest | E(Π) | V(Π) | SK(Π) | RP |
|---|---|---|---|---|---|---|---|---|
| Scenario 1: risk aversion (Antle) | | | | | | | | |
| Vegetables | -3.3903 | -10.0000 | 1.3097 | -0.3871 | 3.4690 | 5.8412 | -2.8902 | 2.7438 |
| Cereals | 1.7517 | -10.0000 | -5.9744 | -0.2098 | -3.1690 | -1.1427 | 1.1434 | -0.4428 |
| Scenario 2: risk neutrality | | | | | | | | |
| Vegetables | 0.9769 | -9.9963 | 2.3303 | -2.3532 | -1.2625 | – | – | – |
| Cereals | 42.7984 | -10.0002 | -1.3587 | 0.8594 | -1.7933 | – | – | – |

Note: Theta parameters from the water equation.

Table A1: Water requirements

| Crop Group | Crop | Water Requirement ($m^3$/ha/year) |
|---|---|---|
| VEGETABLES | Egg plant | 5940 |
| | Peppers | 5560 |
| | Water melons | 5100 |
| | Sweet melons | 5200 |
| | Marrows | 5100 |
| | Tomatoes | 6540 |
| | Okra | 6800 |
| | Haricot beans | 6100 |
| | Cucumber | 4760 |
| | Cabbage | 2800 |
| | Artichokes | 4480 |
| | Onions | 3660 |
| | Black-eye beans | 2200 |
| | Lettuce | 3360 |
| | Cauliflower | 2800 |
| | Celery | 4320 |
| | Parsley | 3660 |
| | Coriander | 3660 |
| | Broad-beans | 2200 |
| | Olives | 5375 |
| CITRUS | Oranges | 10000 |
| | Lemons | 10000 |
| | Grapefruits | 10000 |
| | Mandarins | 10000 |
| CEREALS | Wheat | 5500 |
| | Corn | 6500 |
| | Barley | 5500 |
| | Bran | 5500 |

Table A2

| Zone | Area | Depth to<br>to groundwater | Cost<br>(CYP/$m^3$) |
|---|---|---|---|
| 1 | Kiti | 15.0 | 0.3 |
| 2 | Meneou | 10.0 | 0.2 |
| 3 | Dromolaxia | 18.5 | 0.37 |
| 4 | Alaminos | 8.5 | 0.17 |
| 5 | Mazotos | 6.5 | 0.13 |
| 6 | Anafotia | 12.0 | 0.24 |