The MODERE Model and The Economic Analysis of Farmers' Decisions

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Paper prepared for presentation at the 107th EAAE Seminar *"Modeling of Agricultural and Rural Development Policies"*. Sevilla, Spain, January 29th -February 1st, 2008

Abstract

The MODERE, the Ministry of the Environment Irrigation Decision Model, is a simulation tool which uses mathematical programming methods to reveal the implicit multiattribute objective function lying behind the observed cropping decision. The model takes different criteria such as profit maximization, risk aversion, avoidance of management complexities and so forth into account. In order to determine the feasible combination of attributes of this objective function the model considers the production possibility frontier explicitly as depending on market prices, policy incentives, availability of production factors, water irrigation facilities agronomic vocation and other constraints.

Once calibrated the model becomes a powerful tool to assess the impact of different policy scenarios such as subsidies decoupling, water prices modifications, irrigation technique substitution and so on.

The MODERE is a preference revelation model purposedly designed to be integrated in the Decision Support Platform which is used by the Spanish Ministry of the Environment to compare the policy scenarios whicht are relevant to assess the effectiveness and economic impact of the measures designed to reach the environmental objectives of the Water Framework Directive.

The model is supported by a comprehensive data base built on purpose for its implementation covering almost all the Spanish Irrigation Districts with high spatial detail. This model is currently one of the important modules of the information and decision support systems developed by the Economic Analysis Unit of the Water Directorate at the Ministry of the Environment in Spain.

Key words: Agricultural Economics, Water Economics, Simulation Models.

1. Introduction[1]

European agriculture, which was for a long time considered a traditional, slow moving economic activity strongly dependent on subsidies and public support, is now a sector affected by many political changes and social pressures derived from environmental concerns and trade liberalizations requirements. Furthermore, the sector dynamic has dramatically speeded due to technological innovations, rising world demand for food and raw materials and new uses of traditional crops as energy sources. Subsidies decoupling and market growth have made prices and incentives -rather than trade barriers and public support- the main driving force behind crop decisions and agricultural trends. Meanwhile, the need for new economic analysis tools with the ability to prospect how these changes could affect the environment in general -and water uses in particular- has appeared asa means to understand the policy options at hand and to give answers on how to make agricultural growth compatible with increasing demands of environmental quality and a growing resource scarcity.

[1] The theoretical model and its extensive empirical application to the Spanish Irrigation Districts were developed by the Economic Analysis Group (GAE) of the Planning Division of the Water Directorate of the Ministry of the Environment in Spain. The model is part of the decision platform built to support the implementation of the Water Framework Directive. In this paper only the theoretical model is presented.

Comprehensively there is a growing body of literature providing theoretical and applied models to explain and simulate farmers behaviour. These models are performed to elicit the motivations behind observed farming practices and crop decisions. Many of the existing simulation models have also been successfully incorporated as tools for policy evaluation in many advanced countries[2].

Most of the recent simulation models produced and published in Europe are based on multi-criteria decision methods. These Multi-criteria Decision Models (MCDM) can be found in Romero and Rehman (1984), Romero et al. (1987), Berbel (1989), Berbel et al. (1991), Rehman and Romero (1993), Sumpsi et al (1993), Berbel and Rodríguez-Ocaña (1998), Berbel and Gómez-Limón (2000), Gómez-Limón and Riesgo (2004). In order to obtain relevant policy results, almost all of these models assume that farmers preferences can be represented by a weighted sum of different criteria, such as expected profits, risk and sometimes management issues. The algorithm used to calibrate these preferences (following Romero and Rehman, 1984) has proved that it is effective to reveal the relative weights of the many decision criteria and is commonly accepted as a useful tool to reproduce observed farmers' decisions. The two main characteristics of the MCDM method -the assumption of linear preferences and a calibration mechanism effective but not rooted in explicit economic principles- are nevertheless prone to discussion.

Some other applied models of farmers' decisions use the multi-attribute utility theory. For example Rausser and Yassour (1981) and Delforce and Hardaker (1985) try to provide a clearer intuition of the logic behind farmers' decisions using standard economic analysis. To find models using a preference representation coherent with basic economic principles we need to go back two or three decades to Rausser and Yassour (1981) and Delforce and Hardaker (1985). Moreover the difficulties of running proper elicitation procedures with detailed data and the programming and optimization tools available at this time made these exercises difficult to apply in the detail needed to make them useful for policy assessment and project analysis[3].

All the above mentioned studies provide extensive demonstration that farmers' do not act as profit maximizing agents and show how taking into account other decision attributes such as risk aversion and avoidance of management complexities provides a better explanation of current decisions and a more precise answer to how changes in market and policy environments affect agricultural performance. Some versions of the Multi criteria Models have been developed to include risk avoidance explicitly, as in the "target MOTAD" (Minimization of Total Absolute Deviation), developed by Tauer (1983) and MOTAD (see Watts et al, 1984 for a comparison). Others include a risk premium in the discount factor (e.g. López Baldovín et al, 2005) or provide evaluation of farmer's attitudes towards risk by using alternative utility functional forms (e.g. Torkamani and Haji-Rahimi, 2001).

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[2] A general review of the literature can be found in Dyer et. al. (1992) and Hayashi (1999).
[3] The MODERE has been programmed and implemented in GAMS (General Algebraic Modelling System) allowing the use of an extensive database for an explicit use of the preference revelation theory.

The MODERE (The Ministry of the Environment Irrigation Decision Model) is a simulation tool which uses mathematical programming methods to reveal the implicit multi-attribute objective function behind the observed cropping decision. The model takes different criteria such as profit maximization, risk aversion, avoidance of management complexities and so on into account. To determine the feasible combination of such attributes the model considers the production possibility frontier explicitly as depending on market prices, policy incentives, availability of production factors, water irrigation facilities and agronomic constraints.

Once calibrated the model becomes a powerful tool to assess the impact of different policy scenarios such as the decoupling of subsidies, changes in water prices, irrigation technique substitution and so forth.

3. The Model

3.1. Feasible Crop Decisions

From the farmer perspective any particular crop may be considered as an asset with a known cost in the present and an uncertain value in the future. The size of the investment in each one of these risky assets can be measured by the extension of land devoted to any individual crop (*i*). As the available land is taken as given this investment may be represented as a percentage (x_i) of the available land. Similar to a portfolio each possible farming decision can be easily represented by the vector:

$$x - (x_1, x_2, x_3, \ldots.., x_n); \quad 0 \leq x_i \leq 1 \qquad (1)$$

3.2. Decision attributes and farmers' preferences

Crops are means to some ends. Farmers do not care about crops but about crop decision attributes such as expected profits, risk, likely management problems and so on. These attributes can be analyzed as follows:

a. Expected Returns

Depending on expected market prices, yields and production costs, each possible crop has its own overall expected profit. The sequence of yields and prices in any irrigation district gives farmers an indication of expected income associated to the decision to plant any particular crop. Crop costs include all the financial expenses needed to cover the specific requirements of intermediate inputs, hired labor, capital, financial expenses and so on. For each crop in any irrigation district, costs are obtained from the national system of agricultural accounting.

Expected profits (π_i) measure only the financial expected returns of devoting one hectare to produce the crop *i*. For this reasons other non monetized opportunity costs are not taken into account. These non financial crop costs include some that are private (as the cost of family labor) and others that are social or public (such as environmental costs and scarcity costs). Private non financial costs (such as family labor) as we will mention later might be of some relevance when farmers aim to avoid decisions that are highly complex to carry on. On the other hand, social non financial costs are external to the farmer decision framework but might be important in water policy discussions to which this model pretends to contribute.

The per hectare expected return of each crop (π_i) is the difference between the expected revenue and the expected variable costs of planting this crop. Fixed costs must not be considered as they do not depend on particular crop decisions. For example, in the common situation where water is priced at a flat rate, the corresponding payment does not depend on the choice of one crop or another. Water prices in this case will not explain any difference in crop expected returns and the fixed water price will be in fact irrelevant to explain planting decisions. Nevertheless, the cost of the energy used to apply water to the field must always be accounted for as a variable cost because it depends on the effective water required by each crop.

With this information the per hectare expected profit of a decision ($\pi(x)$), is the sum of the crops per hectare expected returns weighted by the crop shares in the distribution of the available land:

$$\pi(x) = \sum_{k=1}^{n} x_k \pi_k \qquad (2)$$

b. Risk and Uncertainty

Farmers take decisions without perfect knowledge of the yields they will obtain or of the selling prices they will get from the market, apart from other uncertainties related with input prices, labor, water availability in the right time of the season and so forth. Based on previous experience farmers know the expected profit associated to devoting a unit of land to each one of the possible crops.

Using the *modern portfolio theory* (see Markowitz, 1952) we can say that each possible crop is equivalent to an asset of which the returns are random variables. In our case, the quantity invested in any asset may be measured by the extension of land devoted to each crop. This way, the distribution of land among the different crops is formally the equivalent of choosing a portfolio of assets with different expected returns and risk levels.

Crop decisions will then depend on farmers' attitudes toward risk. Risk averse farmers will only accept risky crops if the expected profits of these kind of crops are high enough to compensate them for voluntarily accepting such risk. Risk neutral farmers will always maximize expected profits, and risk prone farmers will not need to ask for higher expected profits in exchange for taking a risky option.

Risk attitudes are determinant to explain farmers decisions but also to explain how farmers' behavior will adapt to institutional changes that modify the balance of expected returns and risk. For example, taking into consideration farmers' attitudes toward risk might be a key factor to explain the effect of a reduction in certain crops production linked to financial subsidies. In this case, the policy shift will lead to a reduction of the affected crops' expected returns and to an increase in the risk associated to planting them (because of the reduction of a kind of income not determined by market prices and other random variables).

Following the practice of portfolio models we can use the standard deviation of the random expected return as a measure of risk. In practice the measure of the standard deviation of any particular decision profile (*x*) requires the previous collection of historical data on prices, yields and costs in order to obtain a clear indication of the different crop returns variance and covariance matrix. The risk associated to a decision *x* can be defined as:

$$\sigma(x) = (x^T VCVx)^{1/2} \qquad (3)$$

Where VCV is the Variance Covariance Matrix of the different crops random returns and x^T is the row or transposed decision vector.

c. Management complexity.

Apart from preferring crops with high and secure profits farmers might also like decisions that are easy to implement. Faced with two alternatives with the same expected profit and a similar risk, the farmer might also prefer the decision which is easier to carry out. Planting, waiting and harvesting may be perceived as better options than alternatives requiring, for example, the occasional hiring of skilled workers, permanent monitoring, a lot of household work and many other actions which, apart from being a nuisance, introduce additional uncertainty concerns (water might not be available in the right moment, skilled workers might be expensive to hire, there might be a shortage of unskilled workers due to strikes or random changes in migration policies and so on).

Voluntarily accepting management complexities implies a real opportunity cost to the farmer. This cost is not as easy to quantify in similar terms as financial or monetary costs. Nevertheless intuition tells us that a farmer will only make a more difficult decision when this opportunity cost is properly compensated by higher expected returns or by a lower risk (in case of a risk averse farmer) or by a combination of both.

Management complexity of cropping decisions is an abstract concept. There is no explicit or direct indicator to measure it. That is why we must rely on one or various proxy observable variables that we assume are highly correlated with the management complexity. Three options can be proposed:

One measure on the complexity of carrying out the decision of planting one hectare of a crop *i* is the overall quantity of labor required during the whole season (l_i). In this case the measure of the labor required by decision *x* is the sum of individual labor requirements l_i weighted by the distribution of land x. Sometimes, farmers may avoid labor intensive alternatives as they imply risks of labor shortage in the peak season, risks related with labor conflicts for example. This variable can be defined by the management complexity indicator z_1 as follows:

$$z_1(x) = \sum_{k=1}^{n} l_k x_k \qquad (4.1)$$

Moreover family labor is somehow different from hired labor. In fact the profits obtained by the farmer are the household income and, apart from paying the fixed production factors, they pay the family labor and compensate the farmer for taking risks. Different from hired labor, family labor is not priced by the market. Additionally, farmers reserve family labor to these important tasks which t are not easy to delegate to hired workers. Understandably farmers will only accept to put more family labor if this is compensated with the expectation of having a higher profit at the end of the season or by a reduction in the risk. The family labor required to carry out the decision of planting the crop *i* can be defined as h_i. Our second candidate to measure the complexity of a decision *x* can then be defined as:

$$z_2(x) = \sum_{k=1}^{n} h_k x_k \qquad (4.2)$$

In a third alternative, management complexity may also be approximately measured by the amount of indirect costs. These costs include the requirements of chemical products, hired works, seed preparation and so on. All these costs are considered absolute terms for the calculation of the expected returns. In this case, the percentage share of indirect costs in the overall costs can be used as an indicator of management complexity. In this case, the indicator can be represented as follows:

$$z_3(x) = \sum_{k=1}^{n} \frac{IC_k x_k}{TC_k x_k} \qquad (4.3)$$

where IC_i and TC_i represent the per hectare indirect cost and the total cost of crop *i* respectively.

The intuition behind this index tell us that when comparing two options with the same expected profit and the same risk, farmers will always prefer the alternative which is easier to put into practice. From the farmers' point of view a decision with a lower management effort would always be better. Having the option to voluntarily accept a more complex to manage alternative, farmers will ask for a compensation consisting of higher expected profits, increased security or a combination of both.

3.3 Eliciting Farmers' Preferences

According to the previous analysis farmers' preferences might be represented by a Multi Attribute Utility Function (MAUF) of the following kind:

$$\underset{x}{Max}\, U(x) = U(\pi(x);\ \hat{\sigma}(x); \hat{z}(x)) \qquad (5)$$

where the vector $x = (x_1, x_2, x_3, \ldots\ldots, x_n)$ represents a decision profile, or portfolio, showing one alternative to distribute the land among the available cropping alternatives.

Each x_i measures the share of land devoted to the crop *i* in such a way that $\sum_1^n x_i = 1$. The set of *n* crop options includes a reservation option (*xn)* consisting in non irrigating a share of the land or, more precisely, devoting a share *xn* of the land to rain fed agriculture.

Farmers have preferences over attributes of the decision profile such as expected profits (measured by the function $(\pi(x))$), risk (measured by the standard deviation of expected profits $(\sigma(x))$), and management complexities measured by the vector $z(x) = (z_1(x), z_2(x), z_3(x))$ as described above.

As a starting assumption farmers are considered risk averse. They have a positive risk premium and are willing to pay (in a reduction of expected financial returns) in order to follow a safer cropping decision. This assumption requires a convex efficiency frontier, meaning that decisions with higher expected returns are associated with higher risk levels. This hypothesis is explicitly tested in the calibration stage of the model. Provided that farmers are risk averse we can define a measure of avoided risk as the difference between the maximum risk (defined by the standard deviation of the maximum expected return: $\bar{\sigma}$) and the standard deviation of the decision profile ($\sigma(x)$). The measure of avoided risk is then:

$$\hat{\sigma} = \bar{\sigma} - \sigma(x)$$

In the same way, farmers avoid complex to manage decisions. If more effort demanding decisions are associated with higher expected returns we can define the avoided management effort as the difference between the complexity measure associated with the maximum expected return ($\bar{z}$) and the complexity index of a particular decision ($z(x)$). This attribute of farmers' preferences can be measured as:

$$\hat{z_i} = \bar{z_i} - z_i(x)$$

3.4 Feasible decisions

The set of feasible crop decisions is constrained by a bundle of restrictions that may be classified as follows:

- First, the set of constraints to be considered is formed by the availability of production factors. In the model the extension of land and the amount of water property rights are considered as fixed production factors. Obviously farmers are not constrained to irrigate all the land. Rain feding agriculture in some portion of the available land being an option to save water in order to get higher profits from heavily water demanding crops. Formally, these production factor constraints can be expressed as:

  $\sum_i x_i \leq 1$ (6.1) Land
  $\sum_i \omega_i x_i \leq \omega$ (6.2) Water

  Where ω_i measures the per hectare water amount that needs to be applied to the field for the crop *i* to get the effective water required according to agronomic and local weather conditions (obtained from soil types, precipitations and evaporation requirements of each crop in the irrigation district). The relationship between the applied water (ω_i) and the effective water ($\overline{\omega_i}$) used by crops depends on the technical efficiency of the irrigations infrastructure ($e = \overline{\omega_i}/\omega_i$) is also taken as given.

- Second, decisions are constrained by the agronomic vocation of the irrigation district (that depends on soil composition, altitude, slope and climate conditions). The easiest way to take vocation into account is by using historical data showing the presence or absence of any crop (i) in the irrigation district. This way we define the parameter $\gamma_i = \{0,1\}$ where a zero value indicates that the presence of the crop i in the area is registered in historical records. This vocation constraint guarantees that only crops historically registered in the area will be allowed in the model. The restriction can be formally represented as follows:

  $\sum_i \gamma_i x_i = 0; \quad \gamma_i \in \{0,1\}$ (6.3) Vocation

- Third, farmers' decisions might be repeatedly made from year to year without yield reductions or soil productivity losses. Except in particular cases where there is evidence of the contrary, farmers' decisions must comply with a st of agronomic requirements, such as crop rotations, in order to avoid soil depletion and then guarantee that current crop decision will also be available in the following years. Agronomic constraints can be represented by a set of m linear restrictions indicating that the total area devoted to a certain kind of crops may not be higher than a certain share of the available land.

  $Ax \leq b; \ A \in \mathcal{R}^{mxn}; x \in \mathcal{R}^n; \ b \in \mathcal{R}^m$ (6.4) Agronomic Constraints.

- Fourth, crop decisions are limited by agricultural policies and other institutional constraints defining the maximum land surface for certain crops or requiring to set aside a portion of land as a condition to get subsidies for certain production supported crops. In order to formally present these constraints, we define the square matrix $B \in \mathcal{R}^{nxn}$ formed by the parameters $\tau_{ij} \in \{0,1\}$ which value is equal to one for some values in the diagonal (where i=j) provided the surface of crop i is constrained somehow by the local government or by the common agricultural policy and equals zero otherwise (values of τ_{ij} outside the diagonal of matrix B, or where $i \neq j$, are always equal to zero).

  The maximum share of an institutionally constrained crop can be represented by the parameter $\hat{x}_i$ ($0 \leq \hat{x}_i \leq 1$ where $\hat{x}_i = 0$ meaning that crop i is forbidden and $\hat{x}_i = 1$ that surface of crop i is unconstrained). Institutional constraints can be represented as:

  $Bx \leq \hat{x}; \ B = \{\tau_{ij}\}; \ \tau_{ij} = 0 \ \forall i \neq j; \ \tau_{ii} \in \{0,1\}$ (6.5) Institutional Constraints

- Fifth, the existence of permanent crops reduce farmers' short term ability to adapt to market and policy changes. In the very short term the surface occupied by permanent crops cannot be modified but this restriction will be relaxed for versions of the model with a longer time horizon.

  In order to include this constraint we define the parameter μ_i with a value of one for any permanent crop and a value of zero otherwise. The baseline surface of any crop is represented by $x^o = x_i^0$. The parameter $\theta\ (0 \leq \theta \leq 1)$ represents the maximum percentage change allowed in the crop i surface. This parameter is equal to zero in the very short term and becomes higher and eventually irrelevant when a longer time horizon is considered. Flexibility to plant and remove permanent crops can be represented by the constraint:

$$\begin{matrix} Px \leq (1+\theta)x_o \\ Px \geq (1-\theta)x_o \end{matrix}; P = \{\mu_{ij}\}; \begin{matrix} \mu_{ij}=0 \ \forall i \neq j \\ \mu_{ii} \in \{0,1\} \end{matrix} \qquad \text{(6.6) Permanent Crops}$$

In the model we assume that other restrictions different from (6.1) to (6.6) are not relevant to define the set of feasible crop decisions. Farmers are assumed to have unlimited access to the inputs and capital markets.

3.5. The Efficiency Frontier

Given the set of attributes $(\pi(x), \hat{\sigma}(x), \hat{z}_1(x), \hat{z}_2(x), \hat{z}_3(x))$, and the set of feasible cropping decisions (defined by constraints 6.1 to 6.6) there is an efficiency frontier with the best combination of attributes (showing the current state of technology, the above defined constraints and the resources endowments).

This frontier is formed by an efficient combination of attributes in such a way that over this frontier it is impossible to improve with respect to one attribute without accepting a reduction in other attributes of the utility function.

Once over this frontier the efficient farmer will find it is impossible to obtain higher expected returns from his/her decisions without accepting to bear a higher risk (provided the farmer is risk averse), or alternatively, without accepting to take a more complex to manage decision (provided the farmer is reluctant to assume management complexities). In the same way, decisions where it is possible to obtain the same expected profit with lower risk or lower management effort do not belong to the efficiency frontier.

3.6. Model Calibration.

If farmers act rationally, observed decisions attributes must be close to the efficiency frontier. This is the key assumption allowing both the economic understanding of farmers behaviour and the preference revelation mechanism used by our simulation model.

The calibration of the model consists in approaching the attributes of the observed decision to the efficiency frontier. In practice, for most real life farmers' decision frameworks the efficiency frontier cannot be analytically represented by a single equation and except from some oversimplified examples it is almost always impossible to represent such a frontier showing each decision attributes as a mathematical function of each other. Nevertheless this frontier can be numerically obtained by solving many optimization problems. For example, using a standard optimization software we could obtain the maximum expected profits attainable by each conceivable risk level. In an equivalent way we might obtain the minimum risk associated to each level of expected returns. Similarly for any feasible combination of risk and expected profits, the minimum quantity of hired labor (or, alternatively, the minimum family labor or the minimum proportion of direct costs over total costs) can be obtained.

The calibration of the model does not require knowing the entire efficiency frontier in advance. As explained below, all we need is , first to show that the observed decision attributes are close to the frontier, second, that the attributes considered are relevant to understand farmers' decisions, and, third, that the efficiency frontier is convex in the surroundings of the observed attributes.

We understand the calibration of the model as the logical process designed to bring the observed decision attributes as close as possible to the relevant efficiency frontier. In the first stage we test the hypothesis that farmers maximize the decisions expecting financial returns. If this hypothesis is accepted (and the observed decision is in fact the maximum expected returns decision), we can say that expected financial returns is the only relevant attribute of the utility function. In this case we might also conclude that farmers are risk neutral and management complexities are not of their concern when deciding what to grow in the field. This kind of conclusion is nevertheless unlikely, given the abundant evidence that farmers do not maximize expected profits. To measure the goodness of the calibration procedure we use the relative distance between the observed attributes and the efficiency frontier expressed in relative terms. This way, with only one attribute, this distance can be measured as:

$$\varepsilon_d^1 = \frac{\pi^* - \pi_o}{\pi^*} \qquad (7.1)$$

where the star indicates the optimal value and the o sub index indicates the observed decision value.

When farmers do not maximize profits (or the distance between the observed and the expected profit is high) we consider the hypothesis that farmers are willing to consider low profit decisions provided the associated risk is lower than in the maximum returns decision. Two conditions become necessary to accept a new attribute as relevant to understand farmers' behaviour. First, taking the new attribute into account must leave the farmer close to the efficiency frontier. Second, the new attribute must be economically relevant in the sense that it must have an opportunity cost. For risk adverse farmers safer decisions need to be associated to lower profits. In this case safety is a good with a price (in other words, there is a positive risk premium). In this context, farmers will only accept risky decisions if they are properly compensated by the market with high enough expected profits[4]. This case is represented in Figure 1. As we can see in the figure, provided the efficiency frontier is convex (there is a cost to be paid in exchange of lower risk) taking into account risk moves the observed decision attributes closer to the efficiency frontier.

[4] On the contrary, if the market does not give compensation for risky decisions the farmer will always prefer higher expected returns no matter how risk averse he or she was.

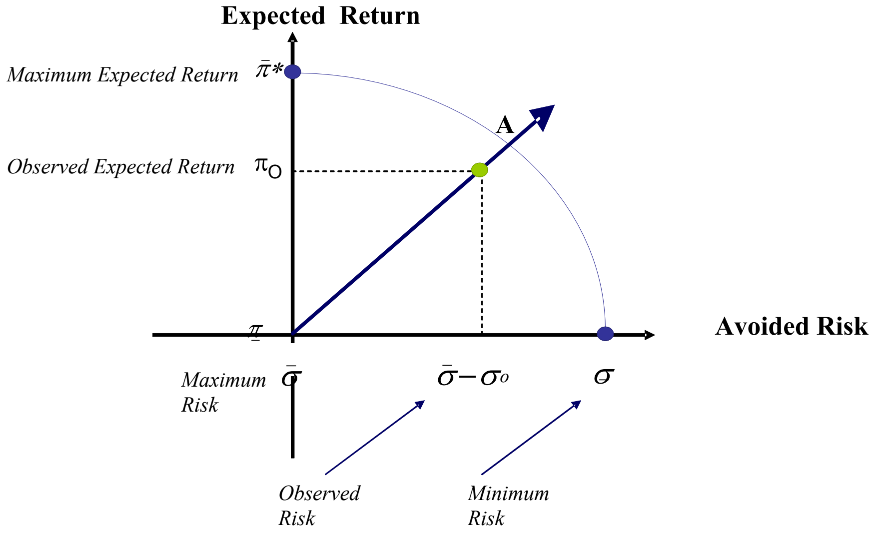

Figure 1. The Efficiency Frontier with Two Attributes

The new distance between the observed and the efficiency frontier can be measured with respect to a point A on the efficiency frontier[5]. The approximation error can be measured by the distance from the observed decision with respect to the efficiency frontier, as follows:

$$\varepsilon_d^2 = \left(\left[\frac{\pi_A-\pi_O}{\pi_A}\right]^2 + \left[\frac{\hat{\sigma}_A-\sigma_O}{\hat{\sigma}_A}\right]^2\right)^{1/2} \quad (7.2)$$

The criteria to decide whether risk and expected profits provide a better explanation of farmers´ decisions will depend on the size of the relative distance with respect to the efficiency frontier. In other words, provided risk avoidance has an opportunity cost, we might accept that this attribute is relevant to understand current farmers' cropping decisions if $\varepsilon_d^2 < \varepsilon_d^1$. The difference between these two calibration errors gives us the measure of how the adjustment improves when risk aversion is considered as an attribute on the implicit farmers' preferences.

The above mentioned procedure continues by sequentially introducing new attributes one by one and by testing step by step that the two necessary conditions to accept a new attribute as relevant are met. These conditions are, first, that the new attribute has a positive opportunity cost (tested by the convexity of the efficiency frontier), and, second, that taking the new attribute into consideration brings the current farmer's decision closer to the efficiency frontier (measured by the distance of observed decision attributes and the set of attributes in the efficiency frontier). For example, the type d error with three attributes can be measured as:

[5] Attributes values for this point can be obtained by solving a profit maximization problem with a new restriction consisting in profits being in the same proportion to risk as in the observed decision. Equivalently we might find the maximum profits over a ray crossing both the origin and the observed attributes as shown in figure 1.

$$\varepsilon_d^3 = \left(\left[\frac{\pi_A - \pi_0}{\pi_A} \right]^2 + \left[\frac{\hat{\sigma}_A - \hat{\sigma}_0}{\hat{\sigma}_A} \right]^2 + \left[\frac{\hat{s}_A - \hat{s}_0}{\hat{s}_A} \right]^2 \right)^{1/2} \qquad (7.3)$$

The calibration procedure then consists in minimizing the type d error. This type d error measures the distance between the attributes of the observed decision and the attributes of the efficiency frontier considering only th attributes that are economically relevant.

3.7. Farmers’ Preferences and Model Calibration

Once the farmer’s decision is shown as close as possible to the efficiency frontier, the second stage consists in obtaining the farmers’ preferences that explain the observed decision as a utility maximizing choice.

Taking into account the relevant decision attributes obtained in the calibration stage, the multi attribute utility function is the one that is able to represent farmers’ preferences in such a way that the observed decision becomes the optimal choice. Using basic economic principles and knowing the efficiency frontier in the surroundings of the observed decision it is possible to integrate such utility function.

From the observed decision and the opportunity cost of the relevant attributes it is possible to integrate an ordinal utility function. Rational decisions imply that in equilibrium farmers’ marginal willingness to pay in order to improve in one attribute with respect to any other is equal to the marginal opportunity cost of this attribute with respect to the other. In other words, marginal transformation relationship between any pair of attributes over the efficiency frontier is equal in equilibrium to marginal substitution relationship between the same pair of attributes over the indifference curve tangent to the observed decision.

The calibration model allows us to obtain the relative opportunity cost of each one of the relevant attributes with respect to one another. This opportunity cost is measured by the marginal transformation relationship and can be obtained numerically by solving partial optimization problems in the proximity of the observed decision. The value obtained this way is the marginal substitution relationship between the same pair of attributes. Figure 2 shows this way of reasoning for a point over the efficiency frontier.

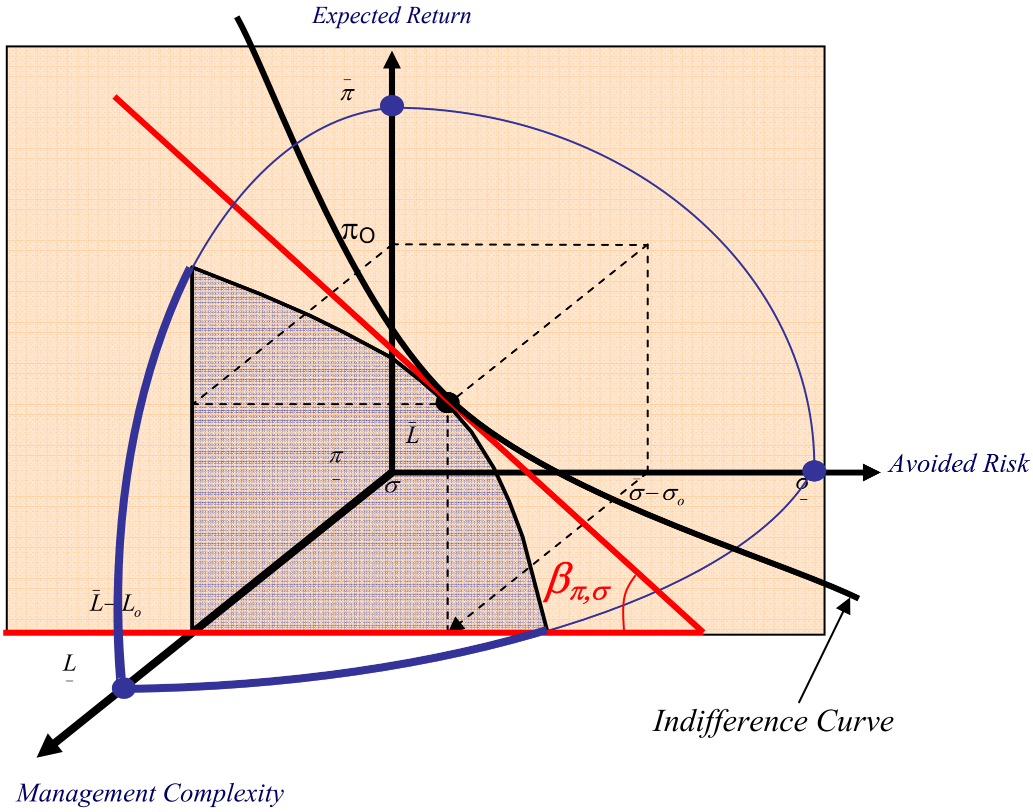

Figure 2. Preference Revelation

As shown in the figure, when deciding on a combination of expected returns and risk bearing while maintaining the management complexity constant, the optimal choice corresponds to the observed decision where the marginal cost of risk avoidance in terms of reduced returns is equal to the slope $\beta_{\pi,\hat{\sigma}}$. A similar analysis can be performed for any pair of attributes. Optimal farmer's choices can be formally represented as:

$$MTR_{\pi,\hat{\sigma}} = \beta_{\pi,\hat{\sigma}} = MSR_{\pi,\hat{\sigma}} = \frac{\partial U/_{\partial\hat{\sigma}}}{\partial U/_{\partial\pi}} \qquad (8.1)$$

$$MTR_{\pi,\hat{z}_k} = \beta_{\pi,\hat{z}_k} = MSR_{\pi,\hat{z}_k} = \frac{\partial U/_{\partial\hat{z}_k}}{\partial U/_{\partial\pi}} \qquad (8.2)$$

$$MTR_{\hat{z}_k,\hat{\sigma}} = \beta_{\hat{z}_k,\hat{\sigma}} = MSR_{\hat{z},\hat{\sigma}} = \frac{\partial U/_{\partial\hat{\sigma}}}{\partial U/_{\partial\hat{z}_k}} \qquad (8.3)$$

$$MTR_{\hat{z}_k,\hat{z}_l} = \beta_{\hat{z}_k,\hat{z}_l} = MSR_{\hat{z}_k,\hat{z}_l} = \frac{\partial U/_{\partial\hat{z}_l}}{\partial U/_{\partial\hat{z}_k}} \qquad (8.4)$$

Knowing the values of the Marginal Transformation Relationships is equivalent to knowing the Marginal Substitution Relationships and this information might be used to integrate the Multi Attribute Utility Function.

For the MODERE we use the following homothetic Cobb-Douglas specification of the Multi Attribute Utility Function (Cobb and Douglas, 1928):

$$U(\pi, \hat{\sigma}, \hat{z}) = \pi^{\alpha_\pi} \hat{\sigma}^{\alpha_{\hat{\sigma}}} \hat{z}_1^{\alpha_{z_1}} \hat{z}_2^{\alpha_{z_2}} \hat{z}_3^{\alpha_{z_3}} \qquad (9)$$
$$\alpha_\pi + \alpha_{\hat{\sigma}} + \alpha_{\hat{z}_1} + \alpha_{\hat{z}_2} + \alpha_{\hat{z}_3} = 1$$

The preference revelation problem is solved by determining the values of the α exponents. For the attributes that were shown in the calibration stage as non relevant to explain farmers decisions this exponent is equal to zero. For the others a solution can be obtained from the equilibrium conditions by solving the following system:

$$MSR_{\pi,\hat{\sigma}} = -\frac{\alpha_{\hat{\sigma}}}{\alpha_\pi}\frac{\pi}{\hat{\sigma}} = -\beta_{\pi\hat{\sigma}} \qquad (10.1)$$
$$MSR_{\pi,\hat{z}_k} = -\frac{\alpha_{\hat{z}_k}}{\alpha_\pi}\frac{\pi}{\hat{z}_k} = -\beta_{\pi,\hat{z}_k} \qquad (10.2)$$
$$MSR_{\hat{\sigma},\hat{z}_k} = -\frac{\alpha_{\hat{z}_k}}{\alpha_{\hat{\sigma}}}\frac{\hat{\sigma}}{\hat{z}_k} = -\beta_{\hat{\sigma},\hat{z}_k} \qquad (10.3)$$
$$MSR_{\hat{z}_k,\hat{z}_l} = -\frac{\alpha_{\hat{z}_l}}{\alpha_{\hat{z}_k}}\frac{\hat{z}_k}{\hat{z}_l} = -\beta_{\hat{z}_l,\hat{z}_k} \qquad (10.4)$$

Apart from obtaining a Multi Attribute Utility Function able to represent farmers' preferences the model provides us with three error measures that would be useful when evaluating the many simulations results that can be obtained in an applied work. The first of these measures is the one explained above to measure the goodness of the approximation to the efficiency frontier (the error ε_d obtained in the calibration stage). The second error measures how precise the approximation of the calibrated model is to the observed set of relevant attributes (ε_A), and can be represented as:

$$\varepsilon_A = \left(\left[\frac{\pi^* - \pi_0}{\pi^*}\right]^2 + \left[\frac{\hat{\sigma}^* - \hat{\sigma}_0}{\hat{\sigma}^*}\right]^2 + \left[\frac{\hat{z}^* - \hat{z}_0}{\hat{z}^*}\right]^2 \right)^{1/2} \qquad (11)$$

The third error represents how precise the approximation to the cropping decision profile (ε_D) is, and can be represented as:

$$\varepsilon_D = \left(\sum_n \left(x_i^* - x_i^O\right)^2 \right)^{1/2} \qquad (12)$$

Given the detailed set of constraints considered and the database used to construct the model, it allows us to obtain detailed results for many counterfactual scenarios including those related with changes in the agricultural policy and the measures selected to implement the Water Framework Directive in Spain.

4. Final Remarks

The MODERE (Ministry of the Environment Model of Farmers' Decisions) presented in this paper provides a detailed methodology for the calibration of the cropping decisions taken by farmers avoiding most of the shortcomings of the available simulation models used until now in agricultural economics. On the one hand the model is based on sound economic theory offering a clear explanation of farmers' behaviour in terms of opportunity costs and preferences. For the first time the analysis of the opportunity cost of the attributes farmers consider relevant for their production choices are obtained by an explicit analysis of the efficiency frontier in the space of decision attributes.

On the other hand, the model does not require the use of linear utility functions as when standard multi criteria decision models are applied. This means that farmers' marginal willingness to pay does not need to be considered constant over all the feasible decisions set, and also that the cost of getting safer income levels or easier to manage decisions can be explicitly represented and analyzed. In fact, the cost of these attributes of farmers´ preferences is clearly increasing in terms of forgotten expected revenue. The algorithm used to obtain the calibration of the model and to reveal agents' preferences is not only justified by its effectiveness to replicate the observed decisions, but also by its foundations on an economic interpretation of farmers' behaviour supported by reasons and motives that are easy to understand with basic economic principles underlying rational choices.

For the implementation of the model, the Economic Analysis Group at the Ministry of the Environment in Spain has developed a database gathering all the data needed to calibrate the model, to elicit preferences and to run standard policy scenarios. This database was constructed on medium size space units such as irrigation districts, municipalities and agrarian regions (or Comarcas Agrarias).

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