ESTIMATION OF TWO-STAGE MODELS OF MULTICROP PRODUCTION: WITH AN APPLICATION TO IRRIGATED WATER ALLOCATION IN TUNISIAN AGRICULTURE

Nadia BEL HAJ HASSINE* and **Michel SIMIONI****

Abstract - *This paper addresses the issue of multicrop allocation in agriculture with an application to Tunisia. Two modeling framework are combined: (1) a profit function framework which is a dual approach to modeling multioutput production, given the assumptions of input nonjointness and at least one fixed allocatable input, and (2) an endogenous switching econometric model for estimating multioutput choices when some output choices are corner solutions. To illustrate, the paper deals with irrigated water allocation in the area of Nabeul in Tunisia.*

Key-words - IRRIGATION WATER PRICING, NONJOINTNESS, MULTIOUTPUT PRODUCTION, CORNER SOLUTIONS, ENDOGENOUS SWITCHING.

JEL Classification: Q110, Q150.

The authors thank Alison Burrell, Robert Chambers, Michel Moreaux, Giancarlo Moschini, Yves Surry and Alban Thomas for constructive comments on earlier versions of this paper.

* INRA-ESR, ERNA, Université Toulouse 1; CRERI, Université de Toulon et du Var, France.
** INRA-ESR, MAIA, Toulouse, France.

1. INTRODUCTION

Farmers production decisions modeling permits *i.*) the estimation of the allocated amounts of inputs to the different crops, and *ii.*) the analysis of substitution patterns between these crops due to the scarcity of some inputs such as water in dry lands. These decisions involve first the simultaneous choice of the crops and the planted acreage. Then, the allocation of the variable inputs between the chosen crops can be performed. Producers may then choose not to grow one or more of the crops from the set of the field crops common to their region. The purpose of this paper is to present an econometric framework allowing the analysis of such production decisions. More precisely, the proposed framework combines a two-stage model of multicrop production and an endogenous switching econometric model to deal with the issue of multiple corner solutions in farmer's production decisions. To illustrate, an application to irrigated multicrop production in the area of Nabeul in Tunisia is presented.

Several studies adopted a multiple input and output framework to deal with the analysis of farm production technologies (see Shumway, 1983, and Weaver, 1983, among others). Most of them proposed only an analysis of farm-level aggregated input demands due to the lack of crop-level data. Moreover, even if crop-level data are available, the existence of fixed factors which cause the jointness of the crop-level production processes, prevents from the use of crop-level production functions. Just, Zilberman and Hochman (1983) addressed this issue using a primal approach. Their development on modeling non-joint technologies with fixed but allocatable inputs theoretically allows for the estimation of the variable input allocations. But this approach may be intractable for complicated technologies. Chambers and Just (1989) solved this problem using a dual approach based on two-stage profit maximization. In the first stage, the farmer maximizes profit from each crop given the allocation of the fixed inputs to that crop. In the second stage, the farmer allocates the fixed inputs optimally across crops to get a multicrop profit function. This general approach has been applied to water allocation in agriculture: see Moore and Negri (1992), Moore, Gollehon, and Carey (1994a, 1994b), and Moore and Dinar (1995). Here we apply this framework considering that there is only one allocatable fixed input.

A major problem arises in farmers production decisions modeling using crop-level data, from the fact that some farmers may find corner solutions optimal and not to allocate the fixed inputs to some crops. Direct estimation of input demand and output supply equations using the respective subsamples defined by the various observed combinations of crops would then provide estimated coefficients that are biased as pointed out by Heckman (1979). Weaver and Lass (1989) proposed an estimation strategy when only one input may not be used by some farmers. A more general solution is proposed in Huffman (1988) who employs the methodology of endogenous switching in a multivariate econometric model. The crop-level systems of conditional input demand and output supply equations are then combined into one system of unconditional demand and supply equations where each crop-level system is weighted by the probability of occurrence of the corresponding observed combination of crops. Hereafter, we propose a generalization of the Huffman's methodology by deriving these probabilities from the second stage or acreage decision stage mentioned above.

The paper proceeds as follows. Section 2 presents the general economic framework of two-stage input allocation decisions with a fixed but allocatable input and addresses the issue of multiple corner solutions. The endogenous switching econometric model is presented in section 3. A normalized quadratic profit function (Lau, 1976) is then used to approximate the crop-level profit function. Data and aggregation issues are presented in section 4. Special attention is devoted to the consistent aggregation of outputs with respect to the separability assumption implied by two-stage budgeting in presence of fixed allocatable inputs. Section 5 reports the empirical results on the effects of the pricing of irrigated water on acreage decisions and input substitutions. Some conclusions are drawn in section 6.

2. TWO-STAGE BUDGETING WITH ALLOCATABLE FIXED INPUT

Assume the farm as a competitive multiproduct firm with a fixed amount of total farm land. The production technologies are interdependent only through fixed input constraints. Farmers are considered as profit maximizers. As is emphasized by Chambers and Just, farmers decisions making may be characterized in two stages. In the first stage, the farmer maximizes profit from each output given the allocation of the fixed input to that crop. Then, consider the ith crop, $i: 1,\dots,m$. Let the crop-specific profit function defined as[1]:

$$\Pi^i\left(p^i, w, l^i\right) = \max_{x^i}\left\{p^i y^i - w x^i \;\; s.t. \;\; y^i = f^i\left(x^i, l^i\right)\right\} \quad (1)$$

where p^i is the price of the ith crop, w is the vector of the n strictly positive input prices, y^i is the produced quantity of the ith crop, x^i is the vector of the quantities of variable inputs used in the production of the ith crop, and l^i is the allocation of the fixed input to the production of the ith crop with $\sum_{i=1}^{m} l^i = L$, the total quantity of the allocatable fixed input. Without loss of generality, we assume that the information about the producible set of output for the ith crop can be summarized by the production function $f^i(.,.)$. The crop-level profit function

[1] The profit function is twice continuously differentiable, convex, linear homogenous, and monotonic in *(p,w)* (see Chambers, 1988).

defined by equation (1) measures the variable profit or quasi-rents associated with allocating l^i to the ith crop. Under suitable assumptions, the profit-maximizing supply of the ith crop, $y^i(p^i, w, l^i)$, and the allocation of input j to its production, $x^i_j(p^i, w, l^i)$, given a fixed input allocation l^i can be derived from Hotelling's lemma as follows:

$$y^i(p^i, w, l^i) = \frac{\partial \Pi^i}{\partial p^i} \quad (2)$$

$$x^i_j(p^i, w, l^i) = -\frac{\partial \Pi^i}{\partial w_j} \quad j = 1, \dots, n \quad (3)$$

In the second stage, the farmer allocates the fixed input optimally across crops to get a multicrop profit function. If some components of the vector of the maximum allowable fixed input are fixed, as for perennial products like trees, total variable profit is maximized by the optimal allocation of fixed factor to non perennial products. Thus if the total quantity of the fixed allocatable input L is partitioned into L_1, the total quantity of fixed input allowable to non perennial crops and L_2, the total quantity of fixed input allowable to perennial crops, the maximum profit is given by:

$$\Pi(p, w, L) = \max_{l^1, \dots l^K} \left\{ \sum_{i=1}^{K} \Pi^i(p^i, w, l^i) \quad s.t. \quad \sum_{k=1}^{K} l^k = L_1 \right\} \quad (4)$$

where $k = 1,..,K$ denote the K non perennial crops, and p is the vector of the K strictly positive output prices. The fixed input is allocated across crops to equalize their marginal quasi-rents or shadow prices when no corner solutions exist in the maximization involved in equation (4), i.e.,

$$\frac{\partial \Pi^k(p^k, w, l^{*k})}{\partial l^k} = \frac{\partial \Pi^1(p^1, w, l^{*1})}{\partial l^1} \quad k = 2, \dots, K \quad (5)$$

where the l^{*k}, $k=1,..K$, denote the optimal allocations of the fixed input. In the data set analyzed here, two crops may not be grown, or equivalently, no land may be allocated to them[2] . Without loss of generality, let y^{K-1} and y^K possessing zero solutions. Then, the second-stage maximization problem must satisfy:

---

[2] Land is considered as an essential input (Chambers and Just, 1989).

$$\begin{cases} \dfrac{\partial \Pi^k}{\partial l^k} = \dfrac{\partial \Pi^1}{\partial l^1} \quad \forall k = 2,...,K-2 \\ \left(\dfrac{\partial \Pi^1}{\partial l^1} - \dfrac{\partial \Pi^{K-1}}{\partial l^{K-1}} \right) l^{*K-1} = 0 \; and \left(\dfrac{\partial \Pi^1}{\partial l^1} - \dfrac{\partial \Pi^{K-1}}{\partial l^{K-1}} \right) \geq 0 \\ \left(\dfrac{\partial \Pi^1}{\partial l^1} - \dfrac{\partial \Pi^K}{\partial l^K} \right) l^{*K} = 0 \; and \left(\dfrac{\partial \Pi^1}{\partial l^1} - \dfrac{\partial \Pi^K}{\partial l^K} \right) \geq 0 \end{cases}$$

In other words, the farmer can choose not to grow a crop when its marginal quasi-rent is less than the identical quasi-rents of the other crops. Then the farmer's decision rules can be written as

$$y^{K-1} \begin{cases} \neq 0 \; if \; d_1^* \equiv \partial \Pi^{K-1} / \partial l^{K-1} - \partial \Pi^1 / \partial l^1 > 0 \\ = 0 \; if \; d_1^* \equiv \partial \Pi^{K-1} / \partial l^{K-1} - \partial \Pi^1 / \partial l^1 \leq 0 \end{cases} \tag{6}$$

and

$$y^{K} \begin{cases} \neq 0 \; if \; d_2^* \equiv \partial \Pi^{K} / \partial l^{K} - \partial \Pi^1 / \partial l^1 > 0 \\ = 0 \; if \; d_2^* \equiv \partial \Pi^{K} / \partial l^{K} - \partial \Pi^1 / \partial l^1 \leq 0 \end{cases} \tag{7}$$

The optimal supply of the *i*th crop and allocation of input *j* to its production are then given by equations (2) and (3) where the fixed input allocation is given by the l^{*k}, *k=1,..K*, and $l^{K+1},...,l^m$.

3. ECONOMETRIC MODELING AND ESTIMATION PROCEDURE

3.1. The Econometric Model

Our study applies a normalized quadratic profit function as the form of the crop specific profit function (1). Thus, the expression of the *i*th crop specific profit function is given by

$$\Pi^i \left(p^i, w, l^i \right) = \alpha_0^i + \alpha^i p^i + \sum_{j=1}^{n} \beta_j^i w_j + \vartheta^i l^i + \frac{1}{2} \delta^i \left(p^i \right)^2 + \frac{1}{2} \sum_{j=1}^{n} \sum_{h=1}^{n} \gamma_{jh}^i w_j w_h + \sum_{j=1}^{n} \mu_j^i p^i w_j + \theta^i l^i p^i + \sum_{j=1}^{n} \lambda_j^i l^i w_j + \frac{1}{2} \tau^i \left(l^i \right)^2 \tag{8}$$

where Π^i, $p^i, i = 1,...,m-1,$ and $w_j, j = 1,...,n$, are now deflated by the price of the *m*th output. Indeed, the normalized quadratic imposes linear homogeneity on the profit function by specifying profit, output and input prices relative to a numeraire price. Moreover, the symmetry condition, i.e., $\gamma_{jh}^i = \gamma_{hj}^i$, *j = 1,...,n, h=1,..,n,* is imposed.

Direct application of Hotelling's lemma, see equations (2) and (3), to the *i*th crop specific profit function gives rise to estimable expressions of the crop specific profit maximizing supply of the *i*th crop and allocation of input *j* to its production given a fixed input allocation l^i,

$$\begin{cases} y^i = \alpha^i + \delta^i p^i + \sum_{j=1}^{n} \mu_j^i w_j + \theta^i l^i \\ x_j^i = -\beta_j^i - \mu_j^i p^i - \sum_{h=1}^{n} \gamma_{jh}^i w_h - \lambda_j^i l^i \end{cases} \tag{9}$$

Moreover, estimable expressions of the optimal allocation of the fixed input can be obtained by solving the system in equation (5). They are linear in the exogenous variables, i.e.

$$l^i = \nu^i + \sum_{k=1}^{K} \upsilon_k^i p^k + \sum_{h=1}^{n} \eta_h^i w_h + \kappa^i L_1 \tag{10}$$

where the $\nu^i, \upsilon_k^i, k:1,...,K, \eta_h^i, h:1,...,n,$ and κ are simplified coefficients from the parameters of the crop-specific profit functions (see Moore and Negri, 1992 and Moore and al., 1994b). The equations in system (9) are assumed to be stochastic and to contain a random disturbance term we denoted by $u^i, and\ \xi_j^i$ for the $y^i's,$ and $x_j^i's$ respectively. The $l^i's$ equations (10) contain a random disturbance term ζ^i.

Consider now that corner solutions may occur for two crops as observed in the following application. In the previous section, $y^{K-1}, and\ y^K$ denoted the corresponding outputs. Our sample can then be partitioned into four mutually exclusive subsamples based upon the outcomes of the discrete choices on $y^{K-1}, and\ y^K$:

- (S_1) where all crops have nonzero values,
- (S_2) where $y^{K-1} = 0$ and the other productions have nonzero values,
- (S_3) where $y^K = 0$ and the other productions have nonzero values, and,
- (S_4) where $y^{K-1} = 0$ and $y^K = 0$.

For each regime, a zero value of an output implies zero values for the fixed and variable inputs involved in its production. The system of equations to be estimated is given by (9) and (10) with a number of equations varying according to the regimes $S_r, r = 1,..,4$.

The distribution of the observations among the four regimes is conditioned by the outcomes of the second step of the second-stage maximization, i.e., the decision rules (6) and (7). The latent variables d_1^* and d_2^* involved in these decision rules can be approximated by

$$d_1^* = \Psi' W + \varepsilon_1 \tag{11}$$

and

$$d_2^* = \Gamma' W + \varepsilon_2 \tag{12}$$

where *W'=(p',w',L)'*. Ψ and Γ are matrices of parameters to be estimated, and ε_1 and ε_2 are two error terms. These equations define the endogenous switching among the four regimes.

3.2. A Tow-Stage Estimation Procedure

Without loss of generality, consider the supply equation of output *i* in the *r*th regime. Its conditional expectation given this regime is expressed as follows:

$$E\left(y^i / S_r\right) = \alpha_r^i + \delta_r^i p^i + \sum_{j=1}^{n} \mu_{jr}^i w_j + \theta_r^i l^i + E\left(u_r^i / S_r\right) \tag{13}$$

where, *r = 1,..,4* and *i =1,..,K*. The nonrandom distribution of observations among the different regimes implies that $E\left(u_r^i / S_r\right) \neq 0$. A selection bias can occur from the omission of this last term as shown by Heckman (1979). To deal with this issue, we can assume that ε_1, ε_2 and u_r^i have a trivariate normal distribution. Consider the conditional expectation of u_r^i given regime S_1. Its expression is given by:

$$E\left(u_1^i / S_1\right) = \varpi_{1i2}^1 E\left(\varepsilon_1 / \varepsilon_1 \geq -\Psi' W, \varepsilon_2 \geq -\Gamma' W\right) + \varpi_{2i1}^1 E\left(\varepsilon_2 / \varepsilon_1 \geq -\Psi' W, \varepsilon_2 \geq -\Gamma' W\right)$$

where ϖ_{1i2}^1 and ϖ_{2i1}^1 are unknown regression coefficients whose expressions depend on the unknown parameters of the trivariate normal distribution. This equation can be written as:

$$E\left(u_1^i / S_1\right) = \varpi_{1i2}^1 \frac{M_{11}}{P_{11}} + \varpi_{2i1}^1 \frac{M_{21}}{P_{11}} \tag{14}$$

The P_{ij}, *i = 0,1*, and *j = 0,1*, denote the probabilities of any observation being included in each of the four subsamples S_r. More precisely,

$$\begin{cases} P_{11} = P(S_1) = P(d_1^* > 0 \; and \; d_2^* > 0) \\ P_{01} = P(S_2) = P(d_1^* \leq 0 \; and \; d_2^* > 0) \\ P_{10} = P(S_3) = P(d_1^* > 0 \; and \; d_2^* \leq 0) \\ P_{00} = P(S_4) = 1 - P_{11} - P_{01} - P_{10} \end{cases} \quad (15)$$

Moreover, if φ and Φ denote the density and the distribution functions of a standard normal variable respectively, and if ρ denotes the correlation between ε_1 and ε_2, the expressions of M_{11} and M_{21} are given by:

$$M_{11} = \varphi(\Psi' W)\left[1 - \Phi\left(\frac{-\Gamma' W + \rho \Psi' W}{\sqrt{1-\rho^2}}\right)\right] + \rho\varphi(\Gamma' W)\left[1 - \Phi\left(\frac{-\Psi' W + \rho \Gamma' W}{\sqrt{1-\rho^2}}\right)\right] \quad (16)$$

$$M_{21} = \varphi(\Gamma' W)\left[1 - \Phi\left(\frac{-\Psi' W + \rho \Gamma' W}{\sqrt{1-\rho^2}}\right)\right] + \rho\varphi(\Psi' W)\left[1 - \Phi\left(\frac{-\Gamma' W + \rho \Psi' W}{\sqrt{1-\rho^2}}\right)\right] \quad (17)$$

Formulas for $E(u_r^i / S_r)$ involving the expressions of M_{1r}, M_{2r} and $P(S_r), r = 2,..,4$, can be derived in a similar way (Bel Haj Hassine, 1997).

Then, the estimation procedure runs as follows. In the first step, maximum likelihood estimates of Ψ, Γ, φ and ρ are recovered by estimating a bivariate probit model based on the decision rules (6) and (7) in the following way (Heckman, 1976):

We define two dummy variables d_1 and d_2 such that:

$$d_1 \begin{cases} 1 & if \;\; d_1^* > 0 \\ 0 & if \;\; d_1^* \leq 0 \end{cases} \quad (18)$$

$$d_2 \begin{cases} 1 & if \;\; d_2^* > 0 \\ 0 & if \;\; d_2^* \leq 0 \end{cases} \quad (19)$$

The probabilities $P_{ij}, i = 0,1 \; and \; j = 0,1,$ satisfy:

$$P_{d_1}(d_1 = 1) = \Phi(\Psi' W) = P_{11} + P_{10}$$
$$P_{d_2}(d_2 = 1) = \Phi(\Gamma' W) = P_{11} + P_{01}$$
$$P_{d_1 d_2}(d_1 = 1, d_2 = 1) = F(\Psi' W, \Gamma' W, \rho) = P_{11}$$

where F denotes the distribution function of standard bivariate normal variables with correlation coefficient ρ. The maximum likelihood estimates of Ψ, Γ, φ and ρ may be found by an iterative procedure starting from initial maximum likelihood estimates of the univariate probit models (Ashford and Snowden, 1970; Amemiya, 1974).

The estimated values of these parameters allow for the computation of the probabilities P_{ij}, i = 0, 1 and j = 0, 1, and the M_{ij}, i =1, 2 and j = 1, ..,4. These values are then used as explanatory variables in the equations defining the $E(u_r^i / S_r)$, r = 1,2,3,4 (see (13)). The same procedure will be followed for fixed and variable input demand equations.

In the second step, the conditional supply (demand) equations are corrected for selection bias and then combined to obtain unconditional structural supply (demand) equations as proposed by Huffman (1988). More specifically, instead of using only the nonzero observations on y^i, x_j^i and l^i , the unconditional supply and demand system can be fitted using Three Stage Least Squares to the total number of observations as follows:

$$\begin{cases} E(y^i) = \sum_{r=1}^{4} E(y^i / S_r) P(S_r) \\ E(x_j^i) = \sum_{r=1}^{4} E(x_j^i / S_r) P(S_r) \quad i = 1,..,K \; and \; j = 1,..,n \\ E(l^i) = \sum_{r=1}^{4} E(l^i / S_r) P(S_r) \end{cases} \tag{20}$$

where

$$\begin{cases} E(y^{K-1} / S_2) = E(y^K / S_3) = E(y^{K-1} / S_4) = E(y^K / S_4) = 0 \\ E(x_j^{K-1} / S_2) = E(x_j^K / S_3) = E(x_j^{K-1} / S_4) = E(x_j^K / S_4) = 0 \\ E(l^{K-1} / S_2) = E(l^K / S_3) = E(l^{K-1} / S_4) = E(l^K / S_4) = 0 \end{cases}$$

4. DATA AND AGGREGATION ISSUES

The area of Nabeul is located in the north-east part of Tunisia, and is a peninsula surrounded by the Mediterranean. Its two main agricultural features are the variety of irrigated crops, which are grown therein, and the multiplicity of water sources. In 1944, irrigated acreage amounted to 50000 hectares, i.e. 16,67 % of Tunisian irrigated total acreage. 25 400, 10 550[3], 3 100, 3 700, 3 500 and 3 400 hectares were respectively devoted to the growth of summer vegetables, citrus fruits, grapes, fruits, winter vegetables and grain. Water resources come mainly from groundwater which provides 228.3 millions of cubic meters each year. The other sources are surface water, which is mainly provided by the Sidi Salem barrage in the northwest part of Tunisia[4], deep groundwater, and recycled water. Groundwater has been intensively exploited since the seventies. Moreover, percolation of salt water has resulted from the closeness to the sea and has in part damaged this water resource. The consequent scarcity of groundwater and the size of the dispatching costs of surface water should increase the price of water. This should in turn adversely affect many crops which are raised in the area of Nabeul, and which intensively demand water to be grown. The evaluation of the effects of the irrigated water pricing on acreage decisions and input substitutions may then enable to draw some trends in the agricultural production patterns.

The data we use for the regression analysis combine cross-section and time series observations of 15 villages for 5 years, 1989-1994. They are from 1990, 1992 and 1994 Tunisian Ministry of Agriculture's surveys of irrigated farms[5]. They include very desegregated data on the produced crops, cropland use, purchased inputs and irrigation water use by crop for each village. Two categories of variables are then defined: output and input quantities and prices, weather and soil quality indexes. Eight aggregated outputs are constructed from these data:

- winter vegetables with high water requirement (about 7 300 m^3/ha): artichokes, strawberry, allium,
- winter vegetables with low water requirement (about 1 700 m^3/ha): garlic, garden peas, carrots,
- summer vegetables with high water requirement (about 7 000 m^3/ha): tomatoes, peppers, melon,

---

[3] 74 % of Tunisian total acreage devoted to the production of citrus fruits.

[4] In the 80^{th}, a plan of surface water supplying from the northwest resources to the northeast needs was undertaken for promoting the production of citrus fruits in the northeast.

[5] The Tunisian Ministry of Agriculture is composed of different cells called CRDA (Regional Agricultural Commissariat) and situated in every governorates. These units collect every three months detailed data on produced outputs, cropland use, purchased inputs and irrigation water use by each farm. These data are then enumerated in biannual irrigated farm surveys.

- summer vegetables with low water requirement (about 4 200 m^3/ha): mainly potatoes,
- grapes: wine grapes, dessert grapes,
- citrus fruits: mandarin, lemon,
- fruits: apples, pomegranates, pears, quinces,
- grains: wheat, fodder.

Two of these outputs are not grown some years by some villages: winter vegetables with high and low water requirement.

The assumption of weak separability between the aforementioned eight groups of outputs permits to construct aggregate price and quantity indexes and to summarize production decisions to allocation choices between these groups of outputs. This separability assumption implies the independence of the marginal rates of transformation between outputs in a given group from the levels of variable inputs and the allocation vector of the fixed input between all the other products. A consistent aggregation of outputs into each group of non perennial products must then take into account the allocation of the fixed input between them. We used the aggregation procedure proposed by Coyle (1993) which allows for an implicit treatment of this problem (Bel Haj Hassine, 1997).

Table n° 1: Descriptive Information for Selected Variables

	W. veget. HWR[a]	W. veget. LWR	S. veget. HWR	S. veget. LWR[b]	Grapes	Citrus Fruits	Fruits
Production (tons)							
Mean	301.6	4418.5	27656.2	7889.5	881.95	11821.86	611.12
Standard Deviation	584.8	5389.6	35836	6337.4	1444	19798	643.7
Yield ($/ha)							
Mean	10181	3591.2	6677.2	3596	2431	7300	1283
Standard Deviation	9231	1065	1632	377.6			
Acreage (ha)							
Mean	40	243.3	1156.4	564.8	229.4	674.6	234.4
Standard Deviation	61.53	219.4	1396.16	438.7	386.2	1082.6	262.6
Water Demand (mm^3)							
Mean	0.23	0.5	7.54	1.2	0.94	4.97	1.36
Standard Deviation	0.36	0.82	8.7	0.82	1.68	7.83	1.6
Water Price ($/$m^3$)							
Mean	0.041	0.041	0.041	0.041	0.041	0.041	0.041
Standard Deviation	0.006	0.006	0.006	0.006	0.006	0.006	0.006

[a] *Winter vegetables with high water requirement.*
[b] *Summer vegetables with low water requirement.*

The villages irrigate with groundwater and surface water. Binding constraints on groundwater extraction are imposed by the state institutions due to the risk of salt water percolation. Water price is fixed by the Tunisian Ministry of Agriculture and is highly lower than the real cost of water extraction and distribution. The other variable inputs correspond to fertilizers, labor and capital. We considered capital as a variable input because it is mainly rented by the Ministry of Agriculture to the farmers. An evaluation of the cost of use of the equipment per hour was annually established by the Tunisian Ministry of Agriculture. Following Diewert (1976), the ideal price and quantity indexes are used for the aggregated variable inputs and the perennial outputs.

Two climate variables represent expected weather conditions for a season: county-level precipitations and cooling degree-days. They are based on thirty year averages of Nabeul's Department of Agriculture. Table n° 1 gives some characteristics of the sample.

5. IRRIGATED WATER ALLOCATION

The quadratic profit function defined in equation (8) is normalized by grain's price index[6]. Crop-choice decision equations (11) and (12) are estimated with bivariate probit model using LIMDEP software. This model fit the data relatively well with *pseudo-R^2* being of 0.62 and 0.59 respectively. Then the system (20) of four non-perennial output supply, input demand and land allocation equations is estimated by 3SLS using *GAUSS* software.

The system (9) for the three perennial crops is estimated by SURE and the parameters from the eighth crop, i.e. grain, are obtained residually.

Our interest residing in quantifying the effect of water price on multicrop production, the econometric results produce three general findings concerning the price water effects, the water demand and input prices effects, and the land allocation. Note that the econometric results for the non-perennial crops are decomposed to present the estimates conforming to each regime S_1 to S_4. Since every crop-level system is weighted by the probability of occurrence of the corresponding observed combination of crops, we obtain four estimates for each parameter.

The results reported in the following tables indicate that overall the model fit the data relatively well. The estimation results under regime S_1 are however the most significant because this regime is the most representative group of observations.

---

6 The use of grain price as a deflator does not alter the linear form of the supply function. Indeed, a necessary condition for input nonjointness is $\frac{\partial y^i}{\partial p^j} = 0$, for every $i \neq j$ (Lau, 1972). This condition induces the independence of y^i from the grain price index and maintain the linearity of the supply function.

5.1. Price Water Effects

Table n° 2 summarizes the estimated parameters of water price in crop choice, land allocation, output supply, and water demand functions in each regime S_1 to S_4. The major findings consist in the significant impact of water price on crop choices and land allocation decisions. Water price parameter is significant at the 10% level in most equations of the fixed allocatable input, while it is rarely negative and significant in short run water demand and output supply equations. Cropland allocation decisions for winter and summer vegetables appear to depend on the level of water price. Once crops are planted, water price does neither affect producer's short-run water use nor their profit[7]. Note however, that water price does not significantly influences land allocation to winter vegetables with high water requirement (HWR). This result must be used with caution because of the limited number of observations in the sample[8].

Table n° 2: Price Water Effect

Non-perennials	Crop choices	Land allocation	Supply	Water demand
S_1				
W. Veget.. HWR	-2.55	0.011	0.038	-0.014
W. Veget. LWR	-18.15*	-0.66*	0.001	-0.006
S. Veget. HWR		-0.18*	-0.18*	0.026
S Veget. HWR		0.05	0	-0.001
S_2				
W. Veget.. HWR	-2.55	-0.6	1.09	-0.42
W. Veget. LWR				
S. Veget. HWR		3.66*	1.21*	0.406
S Veget. HWR		0.25*	0.37*	0.57*
S_3				
W. Veget.. HWR				
W. Veget. LWR	-18.15*	1.16**	-0.09	0.15
S. Veget. HWR		-3.17*	0.15	-0.164
S Veget. HWR		0.65**	0.56**	-0.65*
Perennials				
Grapes			0.23**	18.8
Citrus fruits			-2.83*	12.98**
Fruits			-2.72*	2.00

* and ** denote a significant coefficient at 10 % and at 1 %, respectively.
The estimated results for regime S_4 are not reported due to the scarcity of observations in this group.

[7] Similar results were found by Moore and al. (1994b).

[8] In view to expand winter vegetable HWR production, farmers in the region of Nabeul are following special training programs to improve their cultural practices.

The results show that an increase of water price would induce land reallocation among crops in each regime. Some land allocations increase in water price while others decrease if total irrigable land requirement remains unchanged in every village. For example, consider the regime S_1 where all the four non-perennial crops are grown. Then an increase in water price would reduce land allocation to winter vegetables with low water requirement (LWR) and summer vegetables with high water requirement (HWR). Then the total planted irrigated area would decrease. Now, if winter vegetables LWR are not grown as in regime S_2, more land would be allocated to summer vegetables LWR and HWR when water price increases. In regime S_3, land allocation to summer vegetables HWR would decrease while the areas allocated to winter vegetables and summer vegetables LWR would tend to increase with water price increase. To sum up, the results show that an increase in water price would globally lead to an extension of the areas allocated to winter and summer vegetables LWR while land allocation to summer vegetables HWR would decrease[9].

The estimates of output supply and short-run water demand functions for perennial crops show a significant impact of water price in the supply functions while the water price parameter is not negative and significant in water demand functions. The results show that water price changes involve some supply substitutions between perennial crops with different water requirements. An important decrease of citrus fruits and fruits supplies would be observed with water price increase while grapes supply would increase.

5.2. Water Demand and Input Price Effects

Table n° 3 reports for each own-crop water demand and each regime, the estimated coefficients of the own-crop land allocation, fertilizer and capital prices. The estimation results indicate a good model fit except for winter vegetables HWR. These results show a significant positive influence of own-crop acreage variables in explaining short-run water use for all crops. These results indicate how a marginal increase in the crop acreage rises the quantity of water allocated to that crop. Particularly an important increase in water demand for summer vegetables and citrus fruits would be involved by a marginal increase in their land allocations.

The major findings reported in tables n° 2 and n° 3 consist in a significant effect of water price increase on land allocation decisions rather than on short-run water demand. Crop acreage is, on the other hand, a significant determinant of water use. The price of water seems to induce an indirect effect on water

---

[9] Except when winter vegetables LWR are not grown.

demand through his effect on acreage allocation decisions.

Table n° 3: Water Demand

Non Perennial Crops

	Winter Vegetables HWR	Winter Vegetables LWR	Summer Vegetables HWR	Summer Vegetables LWR
Cropland				
S_1	0.53*	0.097**	6.39**	1.74**
S_2	-2.4		-0.17	-0.95
S_3		0.6	59.55	11.85*
Fertilizer price				
S_1	0.17**	0.005	-0.016	-0.02
S_2	-0.96		0.6	1.3*
S_3		-0.64	-0.91*	4**
Capital price				
S_1	-0.09	0.01	-0.033	0.04
S_2	3.72**		1.35*	-3.8*
S_3		-0.37	-0.2	-0.64
Adjusted R^2	0.17	0.82	0.95	0.87

Perennial Crops

	Grapes	Citrus Fruits	Fruits
Cropland	4.93**	7.02**	5.38**
Fertilizer price	0.71	-2.26*	0.58
Capital price	-1.58	-3.29*	-0.17
Adjusted R^2	0.97	0.97	0.75

Following Moore and al. (1994b) we performed a numerical analysis of the crop level water use induced by an increase of water price. The results show that a 0.01 DT/ ($1DT \approx 1\$$) increase in water price would induce under regime S_1, a decrease of 66 m^3/ha in winter vegetables LWR water use and a decrease of almost 132 m^3/ha in summer vegetables HWR water use, while summer vegetables LWR water demand would increase of 14 m^3/ha. Concerning perennial crops, decreases of 173 m^3/ha and 227 m^3/ha would be respectively observed for fruits and citrus fruits water demands while water use for grapes would increase by 14 m^3/ha.

Responsiveness of water demand to input prices show a possible substitutability effect between water and the use of other inputs. For example, fertilizer and capital would be substituted to water in winter vegetables HWR production, and fertilizer to water in grapes production.

5.3. Fixed Input Effect

Table n° 4 reports the estimates of the land allocation functions. Overall the model fits the data relatively well. Major cropland allocation functions do not slope upward in their own prices and several estimated responses to crop prices are not significantly different from zero. The ineffective performance of crop prices may be explained by the severe multicollinearity between crop prices that the Huffman's endogenous switching econometric approach generates and which is worsened by the small size of the sample[10].

In spite of their weak performance, the estimated crop price parameters illuminate some substitution patterns between crops. Crop price variations would involve village-level land reallocations. An increase in winter vegetables HWR would decrease the allocated land to summer vegetables HWR. On the other hand, the amount of land allocated to summer vegetables LWR increase with the increase of winter vegetables LWR price.

Table n° 4: Estimated Cropland Allocations

	Winter Vegetables HWR	Winter Vegetables LWR	Summer Vegetables HWR	Summer Vegetables LWR
Crop price				
S_1				
Winter Veget. HWR	0.032	0.06	-0.13**	0.015
Winter Veget. LWR	-0.017	0.02*		0.02**
Summer Veget. HWR	-0.09	-0.2	-0.27*	0.14*
Summer Veget. LWR				0
S_2				
Winter Veget. HWR	-0.95		0.63	-0.7
Winter Veget. LWR	0.16*			-0.11
Summer Veget. HWR	0.89		2.73*	-1.12*
Summer Veget. LWR			-0.17	0.11
S_3				
Winter Veget. HWR		-0.12	0.66	-0.26
Winter Veget. LWR		-0.8		-0.09
Summer Veget. HWR		1.87	-2.03*	-0.5
Summer Veget. LWR			-1.75*	-0.12

10 The same problem was encountered by Moore and al. (1994b).

Table n° 4: Continued

	Winter Vegetables HWR	Winter Vegetables LWR	Summer Vegetables HWR	Summer Vegetables LWR
Total Land				
S_1	0.016**	0.08**	0.06**	0.014**
S_2	0.16**		0.11*	0.02
S_3		-0.02	-0.85*	-0.4*
Fertilizer price				
S_1	0.03		-1.96*	0.46*
S_2	1.89		29.78**	-1.79*
S_3			-11.19	-2.04
Probabilities				
S_1	-1.67	0.6	-0.5*	-0.18
S_2	18.74		2.28	-0.5
S_3		1.08	-12.29**	-2.7
Adjusted R^2	0.68	0.62	0.91	0.72

The fixed input constraint performs significantly as a determinant of irrigated production decisions. Coefficients on the land constraint measure the change in acreage allocated to a crop involved by one-acre increase in total land[11]. Land constraint is significant at the 1% for land allocation equations. An increase in total land would particularly profit to winter vegetables LWR and summer vegetables HWR. When winter vegetables LWR are not produced (regime S_2) the fixed input parameter is a significant determinant of winter vegetables HWR and summer vegetables HWR land allocations.

Finally, the results show that bivariate probabilities P_{ij} have a significant effect on summer vegetables HWR land allocation. A decrease in their planting areas would be observed under the regime S_1 (all crops are grown) and S_3 (winter vegetables HWR are not grown). Although not statistically significant, the impact of probability P_{10} (not growing winter vegetables LWR) on land allocation to summer vegetables HWR is positive. This result may explain the positive impact of water price on land allocation to summer vegetables HWR as shown in table n° 2. We may conclude that winter vegetables LWR and summer

[11] The physical constraint requires that, when all crops are accounted for, changes in land allocation sum to one for a change in the land constraint. This is not the case for the region of Nabeul , because the estimation results does not account for irrigable areas that may not be used by farmers some years.

vegetables HWR are competitive[12].

6. CONCLUDING REMARKS

This paper considered the problem of corner solutions in farm-level production decisions. A combination of a two-stage multicrop production model and an endogenous switching econometric model was proposed. This approach is implemented in a sample of villages in the area of Nabeul in Tunisia. The empirical analysis focuses on the effects of water price variations on land allocation, output supply and water demand for each crop. The main findings show that water price performs well in explaining the fixed input allocation among the different non-perennial crops. An increase in water price would involve a significant reallocation in cropland from high water requirement vegetables to low water requirement vegetables. However, the non-perennial crop supply and water demand functions seem not sensitive to water price variations. Concerning perennial productions, water price seems to have a significant negative impact on the supply of crops with high water requirements like fruits and citrus fruits.

Finally the analysis shows that village irrigation water uses depend significantly from own-crop land allocations. An important increase in water demand would be observed with the extension of areas allocated to crops with high water requirements like summer vegetables HWR and citrus fruits. The empirical analysis allows to conclude that the effect of water price on short-run water demand occurs through crop choice and land allocation decisions. Once cropland is allocated the price-induced water conservation measures are no more effective.

[12] Some agricultural reports reveal that some farmers pull up winter vegetables before their term to plant summer vegetables.

REFERENCES

Amemiya T.,1974, "Bivariate Probit Minimum Chi-Square Methods", *Journal of the American Statistical Association*, 69, p. 940-944.

Ashford J.R. and Snowden R.R., 1970, "Multi-Variate Probit Analysis", *Biometrics*, 26, p. 535-546.

Bel Haj Hassine N., 1997, *Tarification de l'eau et agriculture irriguée : le cas de la Tunisie*, Ph. D. thesis, Université des Sciences Sociales de Toulouse.

Chambers R.G., 1988, *Applied Production Economics: a Dual Approach*, Cambridge University Press, Cambridge.

Chambers R.G. and Just R.E., 1989, "Estimating Multioutput Technologies", *American Journal of Agricultural Economics*, 71, p. 980-995

Coyle B.T., 1993, "Allocatable Fixed Inputs and Two-Stage Aggregations Models of Multioutput Production Decisions", *American Journal of Agricultural Economics*, 75, p. 367-376.

Diewert W.E., 1976, "Exact and Superlative Index Numbers", *Journal of Econometrics*, 4, p. 115-145.

Heckman J.J., 1976, "The Common Structure of Statistical Models of Truncation Sample Selection and Limited Dependent Variables and a Simple Estimator for Such Models", *The Annals of Economic and Social Measurement*, 5, p. 475-492.

Heckman J.J., 1979, "Sample Selection Bias as a Specification Error", *Econometrica*, 47, p. 153-161.

Huffman W.E., 1988, "An Econometric Methodology for Multiple-Output Agricultural Technology: an Application of Endogenous Switching Models", *American Journal of Agricultural Economics*, p. 229-244.

Just R.E., Zilberman D. and Hochman E., 1983, "Estimation of Multicrop Production Function", *American Journal of Agricultural Economics*, 54, p. 281-289.

Lau L.J., 1972, "Profit Functions of Technologies with Multiple Inputs and Outputs", *Review of Economic Statistics*, 54, p. 281-289.

Lau L.J., 1976, "A Characterization of the Normalized Restricted Profit Function", *Journal of Economic Theory*, 12, p. 131-163.

Maddala G.S., 1983, *Limited Dependant and Qualitative Variables in Econometrics*, Cambridge University Press, Cambridge.

Moore M.R. and Negri D.H., 1992, "A Multicrop Production Model of Irrigated Agriculture Applied to Water Allocation Policy of the Bureau of Reclamation", *Journal of Agricultural and Resource Economics*, 17, p. 29-43.

Moore M.R., Gollehon N.R. and Carey M.B., 1994a, "Alternative Models of Input Allocation in Multicrop Systems: Irrigation Water in the Central Plains, United States", *Agricultural Economics*, 11, p. 143-158.

Moore M.R., Gollehon N.R. and Carey M.B., 1994b, "Multicrop Production Decisions in Western Irrigated Agriculture: The Role of Water Price", *American Journal of Agricultural Economics*, 76, p. 859-874.

Moore M.R. and Dinar A., 1995, "Water and Land as Quantity-Rationed Inputs in California Agriculture: Empirical Tests and Water Policy Implications", *Land Economics*, 71, p. 445-461.

Shumway C.R., 1983, "Supply, Demand and Technology in a Mutliproduct Industry: Texas Field Crops", *American Journal of Agricultural Economics*, 65, p. 748-760.

Shumway C.R., Pope R.D. and Nash, 1984, "Allocatable Fixed Inputs and Jointness in Agricultural Production: Implications for Economic Modeling, *American Journal of Agricultural Economics,* 66, p. 72-78.

Weaver R.D., 1983, "Multiple Input, Multiple Output Production Choices and Technology in the US Wheat Region", *American Journal of Agricultural Economics*, 65, p. 45-56.

Weaver R.D. and Lass D.A., 1989, "Corner Solutions in Duality Models: a Cross-Section Analysis of Dairy Production Decisions", *American Journal of Agricultural Economics*, 71, p. 1025-1040.

ESTIMATION DES TECHNOLOGIES AGRICOLES A PRODUITS MULTIPLES EN PRÉSENCE DE FACTEURS FIXES : APPLICATION A L'AGRICULTURE IRRIGUÉE EN TUNISIE

Résumé *- Cet article analyse les décisions de production agricole, à partir de l'approche des technologies à produits multiples, avec une application à l'agriculture irriguée en Tunisie. Deux types de modélisation ont été combinés : (i) l'approche duale à la modélisation des fonctions de production à produits multiples sous l'hypothèse d'indépendance des processus de production et d'existence de facteurs de production fixes ; (ii) un modèle économétrique avec observations tronquées pour l'estimation des choix de production en présence de solutions de coin. L'application empirique vise à évaluer les effets d'une variation de la tarification de l'eau sur l'évolution des cultures irriguées et sur la demande de l'eau dans la région de Nabeul en Tunisie.*

ESTIMACIÓN DE LAS TECNOLOGÍAS AGRÍCOLAS PARA PRODUCTOS MÚLTIPLES EN PRESENCIA DE FACTORES FIJOS : APLICACIÓN A LA AGRICULTURA DE REGADÍO EN TÚNEZ

Resumen *- Este artículo analiza las decisiones de producción agrícola estudiando tecnologías para productos múltiples, con una aplicación a la agricultura de regadío en Túnez. Se han combinado dos tipos de modelos : Primero (i) un estudio dual para hacer un modelo de las funciones de producción para productos múltiples bajo la hipótesis de la independencia de los procesos de producción y de la existencia de factores de producción fijos ; luego (ii) un modelo econométrico con observaciones truncadas para la estimación de las opciones de producción cuando hay soluciones de cuña. La aplicación empírica da una evaluación de los efectos de una variación del precio del agua sobre la evolución de los cultivos de regadío y sobre la demanda en agua en la región de Nabeul en Túnez.*