Chapter 5: An Econometric Analysis of Agricultural Production, Focusing on the Shadow Price of Groundwater: Policies Towards Socio-Economic Sustainability.

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The focus of Chapter 5 is on the agricultural sector in the Asopos catchment as it has a significant impact on the status of water in the area. In particular, the aim of the chapter is to estimate the farmers' valuation of groundwater's shadow price for the region of Asopos. In order to achieve that, an agricultural micro-economic data-set from the catchment has been collected through the use of a detailed agricultural questionnaire. As it will be explained in the chapter, the questionnaire focuses on collecting information regarding cultivations, production structures and use of groundwater for irrigation. The objective of the micro-econometric analysis is to uncover patterns of groundwater use and farm efficiency. The chapter presents the derived estimates that make possible the analysis of the impact of different economic policies, -which will be used for the implementation of an optimal, sustainable and integrated water policy- on farmers' profits and social welfare. The chapter finishes with policy recommendations based on the principle of socio-economic sustainability that assures both economic efficiency of farms and concludes with the estimation of groundwater for irrigation shadow price and how this can be used in the design of pumping taxes to reduce pollution and to increase farms efficiency.

1. Introduction

The project aims to evaluate impacts of implementing the EU water directive requiring full cost recovery by 2015. The use of groundwater by farmers located above an aquifer is a very common situation in irrigated agriculture. In such case an estimate of groundwater's shadow price can be used to value the stock of water in green accounting calculations, to help design pumping taxes in order to mitigate externalities associated with groundwater use (Howe, 2002). The Asopos watershed has multiple uses and has significant industrial water pollution and aquifer depletion. Farmers are using pumps illegally. There are concerns for contamination of agricultural products from polluted water (potatoes for example). Based on the data provided in Appendix A, it appears that wheat, potato and olive production are distinct, monoculture systems (with potato irrigated). These crops represent about 80% of total cultivated area. The other major land use is a mix of crops that are mostly irrigated vegetables (about 20% of the cultivated area). Thus, the overall population could be modelled as four strata: 1) rainfed wheat farms; rainfed olive farms; irrigated potato farms; irrigated vegetable/mixed crop farms. More information on the local farms features is presented in Appendix A. The following sections will deal with the estimation of groundwater's shadow price. In section 1, the distance function in production theory is analysed. Section 2 presents the econometric specification, empirical estimation, and results of the estimation of groundwater's shadow price.

2. The Distance Functions in Production Theory

The seminal work by Shephard (1970) provided the theoretical foundations on distance functions in production theory. Grosskopf and Hayes (1993), Färe et al. (1993) and Coelli and Perelman (2000) conducted empirical applications in order to compute shadow prices of either inputs or outputs in various regulated industries. Among the advantages of using distance functions we can distinguish the following:

a) Data on prices is not required in order to conduct the parameters estimation, only quantity data is necessary.

b) No behavioural hypothesis (like profit maximization or cost minimization) are imposed on these models and

c) Firm-specific inefficiencies can be calculated using distance functions.

These are great advantages when tackling water management problems since reliable price data for natural resource inputs is scarce. When firms are heavily regulated they often have a diversity of objectives, and due to regulation or non-optimal management of natural resource industries inefficiencies may arise (in this case, inefficiencies in the use of groundwater). Following Färe and Grosskopf (1990), a dual Shephard's lemma is employed to retrieve firm and input specific shadow prices by using a Shephard's input distance function to characterize technology rather than a cost function. It is considered that an input approach is appropriate in the analysis of the agriculture sector because the managers are likely to have more discretionary control over inputs rather than outputs (Koundouri and Xepapadeas 2004). The restricted input distance function for the *i*th agricultural firm (D_i^R) is defined as:

1) $D_i^R(Y_i, \boldsymbol{X}_i^P, \boldsymbol{X}_i^W; W_i, H, T) = max\left\{\phi_i > 0 : \frac{\boldsymbol{X}_i}{\phi_i} \in L_i(Y_i; W_i, H, T)\right\}$

Where $\boldsymbol{X}_i$ denotes firm-specific vector of m input quantities $(\boldsymbol{X}_i = (\boldsymbol{X}_i^P, \boldsymbol{X}_i^W) \in \boldsymbol{R}_+^m)$, $L_i(Y_i; W_i, H, T) = \{\boldsymbol{X}_i \in \boldsymbol{R}_+^m : \boldsymbol{X}_i \text{ can produce} \boldsymbol{Y}_i \in \boldsymbol{R}_+\}$ denotes the set of all input vectors which can produce the output vector ($\boldsymbol{Y}_i \in \boldsymbol{R}_+$); and ϕ_i measures the proportional reduction in all ($\boldsymbol{X}_i \in \boldsymbol{R}_+^m$) that brings the *i*th firm to the frontier isoquant. Given the restricted cost function in equation (2), Shephard (1970) showed that the restricted input distance function may also be obtained as a price minimal cost function as shown in equation (3).

$$2)\ C_i^R = \left(Y_i, \boldsymbol{P}_p, \boldsymbol{P}_w; W_i, H, T\right) = \min_{X_i^p, X_i^w} \{\boldsymbol{P}_p \boldsymbol{X}_i^p + \boldsymbol{P}_w \boldsymbol{X}_i^w : D_i^R\left(Y_i, \boldsymbol{X}_i^p, \boldsymbol{X}_i^w; W_i, H, T\right) \geqq 1\}$$

$$3)\ D_i^R = \left(Y_i, \boldsymbol{X}_i^p, \boldsymbol{X}_i^w; W_i, H, T\right) = \min_{P^p, P^w} \{\boldsymbol{P}_p X_i^p + \boldsymbol{P}_w \boldsymbol{X}_i^w : C_i^R = C_i^R(Y_i, \boldsymbol{P}_p, \boldsymbol{P}_w; W_i, H, T)\}$$

The Lagrangian of the cost minimization problem in equation (3) is

$$4)\ \Lambda_i = \boldsymbol{P}_p \boldsymbol{X}_i^p + \boldsymbol{P}_w \boldsymbol{X}_i^w + \phi_i\left[1 - D_i^R\left(Y_i, \boldsymbol{X}_i^p, \boldsymbol{X}_i^w; W_i, H, T\right)\right]$$

Applying the envelope theorem to equation (4) gives:

$$5)\ \frac{\partial C_i^R}{\partial W_i} = \frac{\partial \Lambda_i}{\partial W_i} = -\phi_i \frac{\partial D_i^R}{\partial W_i}$$

$$6)\ \frac{\partial C_i^R}{\partial H} = \frac{\partial \Lambda_i}{\partial H} = -\phi_i \frac{\partial D_i^R}{\partial H}$$

In terms of input quantities, the first-order conditions are:

$$7)\ \frac{\partial C_i^R}{\partial X_i^p} = \frac{\partial \Lambda_i}{\partial X_i^p} = P_p - \phi_i \frac{\partial D_i^R}{\partial X_i^p} = 0$$

$$8)\ \frac{\partial C_i^R}{\partial X_i^w} = \frac{\partial \Lambda_i}{\partial X_i^w} = P_w - \phi_i \frac{\partial D_i^R}{\partial X_i^w} = 0$$

In terms of input prices, the first-order conditions are:

$$9)\ \frac{\partial C_i^R}{\partial P_p} = \frac{\partial \Lambda_i}{\partial P_p} = X_i^P$$

$$10)\ \frac{\partial C_i^R}{\partial P_w} = \frac{\partial \Lambda_i}{\partial P_w} = X_i^w$$

$$11)\ \frac{\partial C_i^R}{\partial \phi_i} = 1 - D_i^R(.) = 0$$

Thus, at the optimum $\phi = \Lambda = \hat{C}_i^R$, where $\hat{C}_i^R(\ )$ is the minimum restricted cost (Shephard 1970). But it should be noted that $\hat{C}_i^R(\ )$ depends on the shadow prices that will be estimated. Therefore, in order to obtain $\hat{C}_i^R(\ )$ the assumption suggested by Färe and Grosskopf (1990, p. 125) that firms satisfy a balanced budget is adopted. Thus minimum restricted cost can be estimated since costs must equal revenues and when the distance function (1) is known, we can calculate the derivatives of the restricted cost function from the restricted distance function using:

$$12)\ -\left(\frac{\partial D_i^R}{\partial W_i}\right)\left(\hat{C}_i^R\right) = \frac{\partial C_i^R}{\partial W_i}$$

$$13)\ -\left(\frac{\partial D_i^R}{\partial H}\right)\left(\hat{C}_i^R\right) = \frac{\partial C_i^R}{\partial H}$$

From equations (12) and (13), Proposition 1 can be stated: the accounting price of the groundwater stock of a renewable common property aquifer used for irrigated agriculture, corresponding to a symmetric perfect foresight open loop Nash equilibrium, is equal to the absolute shadow price of the resource derived from the restricted input distance function that describes firm-specific technology, or

$$14)\ -\left(\frac{\partial D_i^R}{\partial W_i}\right)\left(\hat{C}_i^R\right) = \mu_i$$

3. Econometric Specification, Empirical Estimation, and Results

Because all the farmers in our sample are located in the same (small) region, we do not observe any cross-sectional variation in input prices. For this reason, we can only estimate a production function (but not a cost function). Shadow groundwater scarcity rents on groundwater extraction costs are estimated using a stochastic restricted distance function using duality results between distance and cost functions. A translog stochastic input distance function for the case of K inputs and M outputs is estimated following Aigner *et al*., (1977).

To obtain the frontier surface (i.e., the transformation function) we set Di = 1. Further, the restrictions required for homogeneity of degree +1 in inputs are impossed:

$$15a) \sum_{k=1}^{K} \beta_k = 1 \ ; \ \sum_{l=1}^{K} \beta_{kl} = 0 \ \ for\ k = 1,2, \dots, K$$

and

$$15b) \sum_{k=1}^{K} \delta_{km} = 0\ for\ m = 1,2, \dots, M$$

Also the restrictions required for symmetry

$$16a)\ \alpha_{mn} = \alpha_{nm} \quad for\ m, n = 1,2, \dots, M$$

and

$$16b)\ \beta_{kl} = \beta_{lk} \quad for\ k, l = 1,2, \dots, K$$

And the conditions required for separability between inputs and outputs,

$$17)\ \delta_{km} = 0\ for\ k = 1,2, \dots, K\ and\ m = 1,2, \dots, M$$

Thus, we have

$$18)\ ln(D_i/x_{Ki})$$
$$= \alpha_0 + \sum_{m=1}^{M} \alpha_m lny_{mi} + \frac{1}{2}\sum_{m=1}^{M}\sum_{n=1}^{M} \alpha_{mn} lny_{mi} lny_{ni} + \sum_{k=1}^{K-1} \beta_k lnx_{ki}^{*}$$
$$+ \frac{1}{2}\sum_{k=1}^{K-1}\sum_{l=1}^{K-1} \beta_{kl} lnx_{ki}^{*} lnx_{li}^{*} + \sum_{l=1}^{K-1}\sum_{m=1}^{M} \delta_{km} lnx_{ki}^{*} lny_{mi}$$

$i = 1,2, \dots, N\ and\ x_k^{*} = x_k/x_K$

Where *i* denotes the *i*th firm in the sample. It should be noted that homogeneity implies D(y, ωx) = ωD(y, x) for any ω > 0. One of the inputs was arbitrarily chosen and set $\omega = 1/x_K$.

Therefore D(y, x/x_K) = D(y, x)$/x_K$). The frontier function has an error term with two components. The first component is a symmetric error term (V_i) that accounts for noise, which is assumed identically and independently distributed with zero mean and constant variance $[iid \sim N(0, \sigma_v^2)]$. The second component is an asymmetric error term (U_i) that accounts for technical inefficiency, which is assumed to follow an iid distribution truncated at zero (N(v, σ_U^2)).The two components of the error term, V_i and U_i, are independent. Predictions for Di = exp(Ui) are obtained using the conditional expectation Di = E[exp(Ui)|Ωi], where Ωi = Vi-Ui. Changing notation ln(Di) to Ui, equation (18) becomes:

$$19) - ln(x_{Ki}) = TL\left(y_i, \frac{x_i}{x_{Ki}}, \alpha, \beta\right) + Vi - Ui \qquad i = 1,2, \ldots, N$$

Equation (19) is estimated by maximum likelihood. Results are presented in Table 1. Data are drawn from a production surveys conducted in the agricultural region close to the Asopos River Basin in 2009. Farm-specific data includes: area of holding, land use and tenure, area planted, production of temporary and permanent crops, production inputs (including extracted groundwater), administrative costs, personal characteristics of buyers and sellers, employment of holders and family members, labour costs, value of construction works and other investments, indirect taxes and other expenses. The quality of the data-set is limited by the usual difficulties that one encounters when attempting to document inputs and outputs of agricultural activities. Particular difficulties where encountered in the collection of accurate groundwater extraction rates. The data-set has 301 cross sections. The following variables were used:

Output:

y = firm-specific total value of output from production of agricultural crops, measured in Euros and deflated by the wholesale agricultural index.

Inputs:

x1 = farm-specific total area of non-irrigated land (acres),

x2 = farm-specific annual labour costs (Euros),

x3 = farm-specific total value of input costs, including fertilizers, manure, pesticides, fuel and electric power for groundwater extraction (Euros),

x4 = farm-specific yearly groundwater extraction (m3),

x5 = farm-specific total area of irrigated land (acres); the negative of x5 is the dependent variable of the estimated stochastic frontier.

Table 1: Estimated Parameters for the Input Distance Function[a]

Variable	Parameter	ML estimates	standard-error	t-ratio[b]
Constant	α_0	1.48E+00	1.03E+00	1.44E+00
Value of output	α_1	-3.96E-01	1.49E-01	-2.65E+00
Non irrigated land	β_1	6.14E-01	2.32E-01	2.65E+00
Labour costs	β_2	8.65E-02	7.26E-02	1.19E+00
Inputs costs	β_3	2.81E-02	1.15E-01	2.45E-01
Groundwater extraction	β_4	3.89E-01	1.04E-01	3.73E+00
0.5 Squared Value of Output	β_5	3.15E-02	1.21E-02	2.62E+00
0.5 Squared Non Irrigated land	β_6	-2.98E-01	3.49E-02	-8.55E+00
0.5 Squared Value of labour costs	β_7	2.79E-03	4.14E-03	6.75E-01
0.5 Squared inputs costs	β_8	-6.05E-03	1.42E-02	-4.25E-01
0.5 Squared groundwater extraction	β_9	-1.43E-01	8.60E-03	-1.66E+01
Value of output * Non irrigated land	β_{10}	1.43E-02	1.40E-02	1.02E+00

Value of output* Labour costs	β_{11}	-7.80E-03	4.84E-03	-1.61E+00
Value of output* Inputs costs	β_{12}	-2.97E-03	5.09E-03	-5.84E-01
Value of output* Groundwater extraction	β_{13}	-4.57E-03	6.00E-03	-7.62E-01
Non irrigated land* Labour costs	β_{14}	1.40E-02	6.82E-03	2.05E+00
Non irrigated land* Inputs costs	β_{15}	2.80E-02	1.06E-02	2.63E+00
Non irrigated land *Groundwater extraction	β_{16}	-7.19E-02	1.07E-02	-6.74E+00
Labour costs* Inputs costs	β_{17}	-6.56E-03	2.98E-03	-2.20E+00
Labour costs * Groundwater extraction	β_{18}	5.51E-03	3.05E-03	1.80E+00
Inputs costs * Groundwater extraction	β_{19}	2.03E-02	5.87E-03	3.47E+00
Irrigated land	log likelihood	-1.30E+02		
Irrigated land	LR test	4.94E+01		
Irrigated land	σ^2	3.55E-01	4.46E-02	7.96E+00
Irrigated land	Γ	8.91E-01	4.28E-02	2.08E+01

[a]The dependent variable is irrigated land. Number of cross sections is 301; number of time periods is 1.

[b] Hypothesis tests are carried out at 95% confidence level.

Table 1 reports the estimated parameters for the Translog function. As it was expected, the inputs have positive signs and the outputs negative signs. The parameters for squared coefficients and interactions are also reported in the table. The estimated one-sided likelihood ratio (LR) suggests the rejection of the null hypothesis of no technical inefficiency. If the null hypothesis is true, then the generalized LR statistic is asymptotically distributed as a mixture of chi-square distributions. The critical value for this mixed chi-square distribution is 2.706 for a 5% level of significance (taken from Table 1 of Kodde and Palm [1986]). On the other hand, a value of one for γ ($\gamma = \sigma_U^2/(\sigma_U^2 + \sigma_V^2)$) indicates that all deviations are due to technical inefficiency, while a zero value indicates that the deviations from the frontier are entirely due to noise. It should be noted that γ is not equal to the ratio of the variance of the technical inefficiency effects to the total residual variance. Both hypotheses, γ = 0 and γ = 1, are rejected at the 95% level of significance, supporting the existence of technical inefficiency and the choice of a stochastic model, respectively.

Firm-specific technical efficiencies are reported in Table 2. In this case, technical inefficiency means the use of an excessive amount of inputs to produce fixed output levels and could be related to the lack of incentives faced by the operators of the firm. In other words, the use of an economically suboptimal input mix denotes inefficiency in the allocation of resources. This could be the result of exogenous environmental constraints. The existence of technical inefficiency alone does not necessarily imply biased cost function estimates. One use of these results is that these technical inefficiency measures can be used by the regulator for competitive benchmarking in which taxes or subsidies granted to each farm are based on the costs of a similar (in terms of input mix) but more efficient firm. Such a regulatory framework can:

(1) Increase incentives for efficiency among the managers' of the farms and

(2) Using these estimates, the informational asymmetry between the principal (regulators or consumers of agricultural products) and the agent (managers of the farms) can be reduced.

Table 2: Predicted Technical Efficiency Estimates[a]

Firm 1-50	Firm 51-100	Firm 101-150	Firm 151-200	Firm 201-250	Firm 251-301
8.38E-01	6.95E-01	7.18E-01	5.82E-01	7.07E-01	8.22E-01
7.52E-01	7.70E-01	7.85E-01	6.60E-01	7.38E-01	7.69E-01
9.50E-01	8.78E-01	7.85E-01	7.48E-01	7.55E-01	8.51E-01
7.84E-01	3.16E-01	6.48E-01	7.09E-01	7.27E-01	4.67E-01
8.28E-01	6.93E-01	7.28E-01	7.01E-01	5.04E-01	9.03E-01
8.87E-01	3.76E-01	7.23E-01	8.57E-01	6.42E-01	8.35E-01
7.50E-01	8.02E-01	7.59E-01	6.55E-01	7.49E-01	8.88E-01
8.18E-01	7.62E-01	7.10E-01	7.45E-01	7.18E-01	2.30E-01
8.41E-01	7.38E-01	7.85E-01	7.24E-01	7.14E-01	6.37E-01
6.23E-01	8.00E-01	7.41E-01	7.06E-01	7.10E-01	6.05E-01
7.43E-01	8.27E-01	7.07E-01	6.87E-01	5.76E-01	7.46E-01
8.59E-01	7.33E-01	8.23E-01	6.99E-01	8.04E-01	7.49E-01
4.84E-01	7.45E-01	7.73E-01	7.18E-01	6.80E-01	7.74E-01
7.60E-01	7.32E-01	7.46E-01	7.31E-01	6.60E-01	7.91E-01
9.05E-01	6.99E-01	7.70E-01	7.00E-01	2.69E-01	8.01E-01
6.94E-01	6.96E-01	6.48E-01	7.29E-01	2.48E-01	3.93E-01
7.45E-01	7.79E-01	6.49E-01	6.97E-01	2.56E-01	7.99E-01
8.61E-01	7.60E-01	7.48E-01	7.44E-01	7.37E-01	8.85E-01
8.79E-01	8.90E-01	6.89E-01	7.02E-01	7.40E-01	7.19E-01
8.48E-01	8.13E-01	7.15E-01	7.72E-01	6.91E-01	9.34E-01
7.08E-01	6.41E-01	6.94E-01	6.98E-01	6.91E-01	7.78E-01
7.01E-01	7.50E-01	8.27E-01	7.81E-01	9.00E-01	8.18E-01
7.37E-01	4.10E-01	6.74E-01	7.75E-01	6.78E-01	8.26E-01

4.94E-01	4.71E-01	6.54E-01	7.18E-01	7.24E-01	8.00E-01
4.98E-01	7.02E-01	2.07E-01	6.92E-01	7.23E-01	8.02E-01
2.86E-01	7.01E-01	7.19E-01	7.21E-01	7.72E-01	7.26E-01
7.28E-01	7.19E-01	2.80E-01	7.27E-01	8.56E-01	7.97E-01
5.91E-01	7.75E-01	7.21E-01	8.93E-01	7.25E-01	7.41E-01
6.28E-01	7.35E-01	8.15E-01	6.83E-01	6.71E-01	7.42E-01
7.43E-01	6.47E-01	3.35E-01	7.96E-01	7.17E-01	7.51E-01
7.60E-01	5.27E-01	2.55E-01	6.97E-01	7.08E-01	7.96E-01
2.00E-01	6.27E-01	9.10E-01	5.94E-01	8.02E-01	7.44E-01
7.04E-01	3.43E-01	4.39E-01	7.00E-01	7.02E-01	7.11E-01
6.23E-01	8.53E-01	6.88E-01	6.93E-01	6.87E-01	7.37E-01
4.34E-01	7.63E-01	5.64E-01	4.19E-01	3.58E-01	7.31E-01
8.95E-01	7.49E-01	7.18E-01	6.89E-01	4.75E-01	7.36E-01
7.38E-01	2.92E-01	6.99E-01	8.89E-01	9.47E-01	7.40E-01
8.03E-01	8.00E-01	4.82E-01	7.40E-01	4.60E-01	7.87E-01
7.29E-01	6.12E-01	7.30E-01	7.56E-01	6.95E-01	7.05E-01
7.18E-01	8.34E-01	3.57E-01	6.94E-01	8.62E-01	7.65E-01
6.17E-01	1.92E-01	7.53E-01	2.13E-02	3.71E-01	7.64E-01
6.99E-01	8.62E-01	7.19E-01	7.28E-01	7.83E-01	8.37E-01
7.64E-01	7.42E-01	7.45E-01	5.49E-01	7.41E-01	5.76E-01
5.51E-01	8.73E-01	7.10E-01	7.02E-01	9.21E-01	6.53E-01
7.24E-01	8.20E-01	7.14E-01	8.71E-01	9.37E-01	3.92E-01
6.74E-01	7.51E-01	6.66E-01	6.84E-01	7.17E-01	7.57E-01
6.24E-01	7.75E-01	7.88E-01	2.40E-01	8.33E-01	7.96E-01
4.98E-01	8.61E-01	6.77E-01	8.05E-01	8.90E-01	5.33E-01

7.20E-01	5.78E-01	8.89E-01	7.55E-01	8.85E-01	7.93E-01
7.24E-01	8.52E-01	6.97E-01	6.84E-01	5.00E-01	7.40E-01
					8.30E-01

[a]Mean efficiency is 0.69841938

Finally, the mean per cubic meter shadow price estimates are calculated using Proposition 1. The mean annual per farm minimum restricted cost function $\hat{C}_i^R$ is approximated by the mean annual per farm revenue which is measured in Euros, 2005 constant prices: €651,951. The change in the restricted distance function per unit change in groundwater extraction $\left(\frac{\partial lnD_i^R}{\partial lnW_i}\right)$, measured in Euros per cubic meter, is the estimated parameter of the quantity of groundwater extraction from the stochastic distance function estimation: 0.389 €/m^3, the results of which are presented in Table 1. Moreover, D_i^R and W_i are respectively the mean annual estimated distance function (0.139 €/m^3) and mean groundwater extraction per farm (7,173 m^3). Finally, the estimated mean shadow value in situ of per cubic meter groundwater is μ_i= 0.154 €/m^3.

4. Conclusions

Based on an input distance function an in situ shadow price was estimated in a framework independent of cost minimization restrictions. The estimated shadow price of in situ groundwater is €0.154 per cubic metre of water. The estimated groundwater's shadow price can be used to value the stock of water and to help in the design of pumping taxes in order to mitigate negative externalities (e.g. groundwater pollution and aquifer depletion) associated with groundwater use. The use of a distance function approach in estimating scarcity rents is supported by the existence of technical inefficiencies (as it evident from table 2). Therefore, this approach is more appropriate than the restricted cost function approach. Further, these technical inefficiency measures can be used by the regulator. In this case, taxes or subsidies could be granted to each farm based on the costs of a similar (in terms of input mix) but more efficient firm. This kind of policy can increase the incentives towards efficiency, a challenging task when regulation of common property resources is done. Besides, this could reduce the information asymmetry between farmers, consumer and regulators, which is another major issue for the implementation of agricultural policies.

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Appendix A

Type of crops grown in the Asopos region

Crop	**Number of farms**	**Total area (acres)**	**Share of total area (%)**	**Total irrigated area (acres)**	**Share of total irrigated area (%)**
Temporary crops					
Barley	6	230	1.7%	0	0.0%
beetroot	2	4	0.0%	4	0.1%
Carrot	1	15	0.1%	15	0.3%
Corn	1	20	0.1%	0	0.0%
Cotton	7	265	2.0%	265	5.3%
Crop	1	20	0.1%	0	0.0%
Cabbage	6	30	0.2%	30	0.6%
Oats	1	100	0.7%	0	0.0%
Okra	2	7	0.1%	7	0.1%
Onions	21	506	3.7%	486	9.8%
Potatoes	55	2643	19.5%	2638	53.0%
Tomatoes	1	200	1.5%	200	4.0%
Watermelon	1	6	0.0%	6	0.1%

Wheat	72	4595	33.9%	114	2.3%
Beans	1	80	0.6%	80	1.6%
Cauliflower	1	5	0.0%	5	0.1%
Melon	1	70	0.5%	70	1.4%
Peas	1	10	0.1%	10	0.2%
Spinach	1	3	0.0%	3	0.1%
Permanent crops					
Grapes	2	50	0.4%	50	1.0%
Olives	125	3712	27.4%	202	4.1%
Organic olives	2	19	0.1%	0	0.0%
Pistachios	4	160	1.2%	160	3.2%
Vineyard	25	822	6.1%	632	12.7%
Total		**13572**	**100%**	**4977**	**100%**

Wheat, olives, and potatoes are the three major crops grown in the region. They represent respectively 34%, 27%, and 20% of the total cultivated area. About half of the total irrigated area is planted with potatoes (53%). Vineyard and onions represent 13% and 10% of the total irrigated area in the sample, respectively.

Use of irrigation for each type of crop

Crop	Number of farms	Total area (acres)	Total irrigated area (acres)	Share of the area which is irrigated (%)
Temporary crops				
barley	6	230	0	0%
beetroot	2	4	4	100%
carrot	1	15	15	100%
corn	1	20	0	0%
cotton	7	265	265	100%
cabbage	6	30	30	100%
oats	1	100	0	0%
okra	2	7	7	100%
onions	21	506	486	96%
potatoes	55	2643	2638	100%
tomatoes	1	200	200	100%
watermelon	1	6	6	100%
wheat	72	4595	114	2%
beans	1	80	80	100%
cauliflower	1	5	5	100%

melon	1	70	70	100%
peas	1	10	10	100%
spinach	1	3	3	100%
Permanent crops				
grapes	2	50	50	100%
olives	125	3712	202	5%
organic olives	2	19	0	0%
pistachios	4	160	160	100%
vineyard	25	822	632	77%
Total	**340**	**13572**	**4977**	**37%**

Cereals (barley, corn, oats, wheat) are not irrigated in general. Only 5% of the area planted with olive trees is irrigated. Fields planted with cotton, fruits, and vegetables are fully irrigated. Overall, 37% of the total area in the sample is irrigated. The three major products that are grown in Asopos are wheat, olives, and potatoes. We can see from this table that farmers do not combine wheat, olives, or potatoes with the growing of other products in most cases.

Crop	**Farmers growing wheat**	**Farmers growing olives**	**Farmers growing potatoes**

	also grow…	also grow…	also grow…
Barley	2	0	0
Beetroot	0	0	0
Carrot	0	0	0
Corn	0	0	1
Cotton	1	0	1
Crop	0	1	0
Cabbage	0	0	1
Oats	0	0	0
Okra	1	0	0
Onions	2	0	10
Potatoes	3	1	-
Tomatoes	0	0	0
Watermelon	0	0	0
Wheat	-	4	3
Beans	0	0	1
Cauliflower	0	0	0

Melon	0	0	1
Peas	0	0	0
Spinach	0	0	0
Grapes	0	0	0
Olives	4	-	1
Organic olives	0	0	0
Pistachios	0	0	0
Vineyard	0	1	2

The three major crops in the area are wheat, potatoes and olives, which we will consider in turn.

Wheat producers

In what follows we consider the 59 farmers who grow only wheat (overall 72 farmers grow wheat in our sample). The following inputs are considered: fertilizers, pesticides and labour. Fertilizers and pesticides use are farmers' statements while labour is calculated as follows: number of days of casual workers + number of permanent workers x 250. Some basic statistics are shown below. There are all on a *per acre* basis.

Variable	Obs.	Mean	Std. Dev.	Min	Max

Production (tonnes/acre)	59	0.27	0.19	0.02	0.80
Fertilizer use (kg/ acre)	58	17.07	15.37	0.00	60.00
Pesticides use (kg/ acre)	55	0.27	0.60	0.00	2.14
Labour use (days/acre)	59	0.15	0.27	0.00	1.50
Land (acre)	59	70.61	85.86	6.00	500.00

All these statistics are on a *per acre* basis so the figures should not vary too much from one farmer to the other. However we observe very large variations. For example, fertilizer use varies from 0kg/acre to 60kg/acre, with a mean of 17kg/acre. The farmers stating 0 use of fertilizer, pesticides or labour probably did not want to answer or did not know. For these farmers, I have replaced 0 by the median value in the sample of farmers growing wheat only.

Statistics on yield

1 *Acre* - US, = 0.4046873 *ha*, 1 *hectare* (*ha*), = 2.471044 *acre* (US)

Farmers in the sample produce on average 0.27 tonnes per acre, which corresponds to 0.67 tonnes per hectare (or 670kg per ha). The average wheat yield in Greece is 1900 – 3000 kg/ha. The average yield on the sample thus seems a bit low. Once all variables are transformed in logs a Cobb Douglas production function is estimated. Because of the small sample size, it is not reasonable to estimate a Translog production function.

OLS estimation results – Cobb Douglas production function (59 obs)

	Coef.	**Std. Err.**	**P>t**
Fertilizer	0.026	0.093	0.778
Pesticides	0.204	0.119	0.092
Labour	0.140	0.080	0.087
Constant	-0.127	0.146	0.386

In this model the dependent variable is wheat yield. The explanatory factors are the three inputs measured in physical terms: fertilizer use per acre, pesticides use per acre, labour use per acre. The three estimated coefficients have the expected positive sign but only two are significant at the 10% level. However, the model is not significant overall (p-value of the Fisher test is 0.1251). As a consequence the adjusted R-squared is also quite low: 0.0491.

Potatoes producers

In what follows we consider the 34 farmers who grow only potatoes (overall 55 farmers grow potatoes in our sample). Some basic statistics are shown below.

Variable	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
Production (tonnes/acre)	34	2.04	1.13	0.20	5.00

Fertilizer use (kg/acre)	34	20.90	19.71	0.23	75.30
Pesticides use (kg/acre)	25	0.94	1.18	0.00	4.00
Labour use (days/acre)	34	0.80	1.28	0.00	6.50
Water use (m3/acre)	33	2.02	11.61	0.00	66.67
Land (acre)	34	52.15	37.60	7.00	150.00

Here too some figures are really surprising: fertilizer use varies from a low of 0.23 kg/acre to a high of 75.30 kg/acre. Again the zeroes for pesticides and labour do not make much sense.

Olive producers

In what follows we consider the 117 farmers who grow only olives (overall 125 farmers grow olives in our sample). Some basic statistics are shown below.

Variable	**Obs.**	**Mean**	**Std. Dev.**	**Min**	**Max**
Production (tonnes/acre)	104	0.14	0.18	0.02	1.13
Fertilizer use (kg/acre)	112	20.42	18.55	0.00	80.00
Pesticides use (kg/acre)	107	0.19	0.84	0.00	6.00
Labour use (days/acre)	117	2.99	23.20	0.00	250.38
Land (acre)	117	29.91	23.84	5.00	120.00