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Authors	Carlos Mario Gómez, Gonzalo Delacámara, Carlos Dionisio Pérez, Marta Rodríguez, Estefanía Ibáñez, IMDEA
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1. Hydrologic models and the economy

Traditionally, hydrologic models have been based on the water balance concept. They described the flow of water in and out of a system and were mostly used to manage water supply and predict where there may be water shortages/floods (e.g., for irrigation management, flood control, etc.), leaving water demand outside of the model and at the discretion of the user/planner. More recently, holistic models have proliferated. The most innovative characteristic of holistic models is that they integrate water demand (water use patterns, equipment efficiencies, re-use, prices, hydropower energy demand and allocation) on an equal footing to water supply. The design of holistic models is guided by a number of methodological considerations: an integrated and comprehensive planning framework; use of scenario analyses in understanding the effects of different development choices; demand-management capability; and environmental assessment capability. In addition, they tend to be positive models instead of normative ones, i.e., they focus on the observed water demand and supply rather than on finding an optimum water use pattern. As a result, holistic models have succeeded as a tool for water planning and they are now used by river basin authorities worldwide.

There are different hydro-economic models available: WAS in the Jordan river (Fisher et al, 2005); agro-hydro-economic model for Maipú River, in Chile (Cai et al., 2003; Rosegrant et al., 2000); AgriCom Mozart DSS-AMDSS (Heinz et al., 2007); integrated model for drought mitigation in Rio Grande (Ward et al., 2006; Ward and Pulido-Velázquez, 2008); DSS WSM (Assimacopoulos et al., 2001). Holistic models have some advantages but, in order to solve simultaneous equations, components tend to be presented in a too simplistic way. This is particularly visible in the assessment of water demand. In the case of the WEAP software (SEI, 2011) used in this case study, water demand can be obtained in three different ways, depending on data availability. Accordingly, water demand can be derived from a detailed set of final uses or from "water services":

(1) Standard water use method: the user determines an appropriate activity level (e.g. persons, households, hectares of land) for each disaggregated level and multiplies these by the appropriate annual water use rate for each activity.

(2) FAO crop requirements approach: typically used in agriculture, this method assumes for each demand site a set of simplified hydrological and agro-hydrological processes that determine irrigation water demand.

(3) Direct method: demands are directly imported into WEAP from observed values.

Therefore, water demand is included in the model as a value that responds to different policies in a predictable and homogeneous way, which is in turn largely determined by technological and (to a less extent) simple economic parameters.

Although holistic models like WEAP take into consideration water demand, they do not consider into the model the drivers of this water demand. This constitutes the main drawback of their water demand module. As a result, holistic models may be insufficient to explain some paradoxical results that may emerge after a given water policy, namely, an irrigation efficiency increase that increases water demand, also known as Rebound Effect (Khazzoom, 1989; Alcott, 2005 and 2008). Although paradoxical, these outcomes are by no means unexpected: there is a sound economic rationale that explains them (Gutiérrez-Martín and Gómez, 2011; Rodríguez-Díaz et al., 2012; Pfeiffer and Lin, 2012). Therefore, a comprehensive assessment of water demand (and thus a sound forecast) demands more complex socioeconomic models than those included in conventional holistic models. In the particular case of WEAP, water demand forecasts are based on the assumption that water users react in a very straightforward way to water policies (e.g., higher prices will reduce water demand and increase public revenue in a predictable amount), but they do not consider other (relevant) drivers explaining water demand, such as the gross margin (if farmers care about income, a high gross margin may prevent water pricing policies from reducing water demand) or the risk (if farmers care about risk, new restrictions over water use may make the current crop portfolio more risky and the farmer would be willing to change it by a more safe crop portfolio with a higher share of rainfed crops than initially expected) (Gutiérrez-Martín and Gómez, 2011; Gutiérrez-Martín et al., 2013). These apparently paradoxical results are not restricted to agriculture. For example, household water demand may show different price/income elasticities of water demand in different areas and sections of the demand curve, and these elasticities may readapt after a structural change (Martínez-Espineira, 2002, 2003a and 2003b; Martínez-Espineira and Nauges, 2004; Hoffman et al., 2006; Gaudin, 2006). Another relevant critique concerns the impact of water policies over income distribution (which may be highly asymmetric).

Comprehensive hydroeconomic models have several complementary modules that can make them more complex and include additional variables into the equation, but they cannot change the nature of the model. Therefore, we can conclude that since holistic models do not assess the drivers of water demand, they will fall short to accurately predict the total water use stemming from a particular water policy.

In this document we present an economic model to predict agricultural water demand under different water policy scenarios. This model can be used to complement the water supply model of WEAP and obtain more accurate results regarding the impact of water policies over total water use and over the water balance of the basin. In addition, it provides economic results that may be of relevance, such as long term water demand forecasts, agents' preferences, optimum cost recovery policies, etc.

2. Economics and hydrology: the need of a modular approach

Demand refers to the quantity of a product or service that is desired by buyers at a certain price, and it is usually represented through the relationship between price and quantity. However, assuming that the amount of water demanded depends exclusively on the price of water would be over-simplistic. There are many other factors determining the final amount of water used. This includes the prices of other goods (such as complementary inputs in the industrial and agricultural production), income, preferences (which are not restricted to income generation, but also risk avoidance, the avoidance of management complexities, etc.), the nature of the good (with basic commodities facing a higher demand), etc. The interaction among these variables is rather complex, and therefore the impact of a certain policy over total water demand needs to take all of them into account. Nonetheless, holistic hydroeconomic models such as WEAP tend to ignore this part of the problem. Therefore, there is a need to take into account more complex socioeconomic modules in order to obtain more accurate forecasts. The problem is that socioeconomic models are in many cases as much complex and data intensive as their hydrological counterparts, and data availability is not always guaranteed. Consequently, hydroeconomic models may decide to sacrifice complexity and accuracy for the sake of simplicity and implementability.

We think that a modular approach (socioeconomic and hydrological models analyzed comprehensively in separated modules) would be preferable to this over-simplistic holistic approach, especially in those cases when paradoxical results are more likely to occur (Gómez and Pérez, 2012; Gutiérrez-Martín and Gómez, 2011). In the following pages we present two models that determine and estimate the most relevant variables driving the observed agricultural (70-80% of the total water demand in Southern European countries, according to Massarutto, 2003) and household water demand (although this sector is usually presented together with other urban uses, in our application we only consider household demand). These models can be used for policy analysis, to assess the response of water users to different water policies (water pricing, irrigation efficiency increases, drought insurance, etc.) and other related policies (agricultural subsidies, income taxes, increase of the cost recovery rate, etc.). Both models can be calibrated for any area provided that the necessary data is available, and used as a complement for existing hydrologic models. These models and the data used are presented in the next section, while section 4 presents the most relevant results.

3. Data and methods

3.1 Agricultural water demand: the Revealed Preferences Model

In this section we present a revealed preferences model that uses basic microeconomic theory to calibrate and simulate farmers' preferences. We assume that farmers are rational individuals that attempt to maximize their welfare, and therefore their decisions are the result of this welfare maximizing process subject to a set of constraints. Accordingly, in our model farmers decide on crop land surfaces trying to maximize their well-being, which is a function of a set of relevant attributes that may contain expected profit, risk avoidance, managing complexities and/or others. In accordance to the cluster grouping described in the second section, we group farmers by clusters and then we assess the decision of a representative farmer for each cluster (this means that we have five representative farmers). This decision is constrained by technical, economical, policy and environmental variables. We assume that the outcome stemming from this optimization problem results from an underlying utility function that can therefore be calibrated, provided that all the relevant variables are measurable and known. Relevant variables include water prices, irrigation costs, water availability, irrigation efficiency as well as other relevant economic, agronomic and environmental variables.

According to all this we can formulate the following decision problem:

$$\underset{x}{Max}\, U(x) = U(z_1(x);\ z_2(x); z_3(x) \ldots z_m(x)) \quad [1]$$

s.t.: $0 \leq x_i \leq 1$ [2]

$$\sum_{k=1}^{n} x_k = 1 \quad [3]$$

$$X \in F(x) \quad [4]$$

$$z = z(x) \in R^m \quad [5]$$

Where $x \in R^n$ is the decision profile or the crop portfolio showing one way to distribute the land among crops and each x_i measures the share of land devoted to the crop i, including a reservation option (x_n) consisting of rainfed agriculture. Each crop has its own water demand, which may be satisfied or not according to water availability and irrigation efficiency, thus generating a predictable yield/profits with an attached risk, management complexities, etc. (the set of attributes, z).

Farmers have preferences over attributes of the decision profile ($z(x)$). For example, farmers might prefer decisions with high expected profits, highly predictable yields and prices and not too many managing actions apart from planting and harvesting.

Finally, $F(x)$ represents the space of feasible decision profiles, given the resource, policy, economic and balance constraints.

The first problem we need to deal with to reveal farmers' preferences is to know which among the potentially relevant attributes are relevant to explain the observed decision. Our method to answer this question consists in saying that the relevant set of attributes is the one to which the observed decision is closest to the attribute possibility frontier. In real situations this efficiency frontier cannot be defined analytically with a closed mathematical function and the only way to represent it is by numerical methods. One practical solution consists in extending a ray from the origin, passing through the observed decision attributes and extending them as far as possible in the space of feasible attributes. This way we can measure the distance from the observed attributes to the efficiency frontier attributes. We can repeat this procedure for any set of potentially relevant attributes and the best candidate to reveal farmers' preferences will be the one which was closest to its associated efficiency frontier.

The solution of this problem will be an application assigning a distance φ_l $(l = 1, \dots, 2^m)$ to each member of the power set $P(z)$[1]. The relevant set of attributes wil be the one with the lower distance to the efficiency frontier measured by the parameter $(\varphi - 1)$. In synthesis the preference eliciting problem can be presented as:

$$\underset{\tau}{Min}\ \varphi_l - 1 \qquad [6]$$

Where:

$$\varphi_l = ArgMax\left[(\varphi)\ s.t.\, \tau(x) = \varphi(\tau_o(x));\ 0 \leq x_i \leq 1;\ \textstyle\sum_{k=1}^{n} x_k = 1;\ X \in F(x);\ for\ all\ \tau\epsilon P(z)\right]$$

$$l = (1 \ldots.\, 2^m) \qquad [7]$$

By solving this problem we obtain the set (τ^*) of attributes that better explains current farmers' decisions. Among the many factors that might be of relevance in farmers preferences, this set of attributes is the one that takes the observed decision closer to the attribute efficiency frontier. If this calibration procedure takes us close enough to the efficiency frontier we can obtain the implicit value of all the attributes over the efficiency frontier by analyzing how attributes change in the surroundings of this reference point, and this information is all we need to integrate a utility function representing farmers' preferences[2].

Using basic economic principles and knowing the efficiency frontier in the surroundings of the observed decision allows one to integrate such a utility function. Rational decisions imply that in equilibrium farmers' marginal willingness to pay in order to improve one attribute with respect to any other is equal to the marginal

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[1] A power set P(Z) is the set of all the 2^m subsets of the set Z and the power set $P_0(Z)$ is the set formed by the 2^m subsets of the numerical set of observed attributes.

[2] The optimal solution of φ and the reference point in the efficiency frontier provide all the information to measure the calibration error in the atributes space.

opportunity cost of this attribute with respect to the other. In other words, the marginal transformation relationship between any pair of attributes over the efficiency frontier ($\mathrm{MTR_{kp}}$) is equal in equilibrium to the marginal substitution relationship between the same pair of attributes over the indifference curve tangent to the observed decision ($\mathrm{MSR_{kp}}$):

$$\beta_{kp} = MTR_{kp} = MSR_{kp} = -\frac{\partial U/\partial z_p}{\partial U/z_q}; p, q \in (1, .. l); p \neq q \qquad [8]$$

This information for the reference point over the efficiency frontier is enough to integrate a utility function leading to the observed decision as the optimal decision given the existing resource, economic, balance and policy constraints. For example, if we assume a constant returns of scale Cobb-Douglas utility function of the kind:

$$U(\tau) = \prod_{r=1}^{l} z_r^{\alpha_r}; \quad \sum_{r=1}^{l} \alpha_r = 1 \qquad [9]$$

The marginal substitution relationship among any pair of attributes is:

$$-\frac{\partial U/\partial z_p}{\partial U/z_q} = -\frac{\alpha_p}{\alpha_k}\frac{z_k}{z_p} \qquad [10]$$

And the parameters of the Cobb-Douglas utility function are obtained from the following system:

$$-\frac{\alpha_p}{\alpha_k}\frac{z_k}{z_p} = \beta_{kp} \qquad [11]$$

$$\sum_{r=1}^{l} \alpha_r = 1 \qquad [12]$$

The revealed preferences model above provides three types of calibration errors which gives an idea of the accuracy of the model's adjustment:

-The distance between the observed attributes and the attribute efficiency frontier:

$$e_f = (\varphi - 1) \qquad [13]$$

-The distance between the observed attributes and the calibrated ones:

$$e_\tau = \frac{1}{l}\sum_{r=1}^{l}\left(\frac{\left(z_r^{0^2} - \tau_r^{*2}\right)^{1/2}}{z_r^0}\right) \qquad [14]$$

-The relative distance between the observed crop pattern and the optimal one:

$$e_x = \frac{1}{n}\sum_{k=1}^{n}\left(\frac{\left(x_k^{0^2} - x_k^{*2}\right)^{1/2}}{x_k^0}\right) \qquad [15]$$

And the mean calibration error is defined as follows:

$$e = \frac{\sqrt{e_x + e_\tau + e_f}}{3} \qquad [16]$$

Obviously, the calibration error will largely depend on the quality of the data used. For this study, we relied on land use data from CORINE 2000 and the ELSTAT (Hellenic Statistical Service) Agricultural Census. Agronomic water needs were supplied by the calculations of the WEAP Water Balance Model for the Ali-Efenti, while data on yield and prices provided by the Hellenic Organisation of Agricultural Insurance, the Ministry of Agricultural and ELSTAT. Unfortunately, no data was available for indirect and direct costs; this data was transferred from a similar river basin in Spain, the Tagus RB, where data on direct and indirect costs is available as a percentage over total production value in €/ha. Results are conditioned by this assumption.

Table 1. Land use, water demand, agricultural prices and average yield in the Pinios River Basin

Crop	Land use (ha)	Land use (%)	Yield (t/ha)	Price (€/t)	Agronomic water needs (m3/ha)
Alfalfa	6465.7	9.8%	10	170	12393
Maize	12084.7	18.2%	12	180	10349
Cotton	28372.8	42.8%	3.8	410	8370
Sugarbeets	1022.9	1.5%	65	30	10280
Orchards	99.6	0.2%	30	455	11298
Wheat	17583.6	26.6%	3.5	180	0
Olive Trees	596.6	0.9%	7	990	0

Source: Authors' elaboration

4. Results

4.1 Agricultural water demand in the Pinios River Basin

The revealed preferences model is applied to the Pinios River Basin in Greece. The research is conducted in two stages: calibration and simulation. In the calibration stage, we reveal the utility function of a representative farmer in the Pinios RB. Next, we conduct a simulation in which we progressively increase water prices and we assess the effects over water demand (water demand curve), income and employment in agriculture.

4.1.1 Model calibration

Farmers have to decide over the combination of crops to plant subject to a set of feasible options. It is reasonable to think that farmers will choose the crop portfolio that maximizes their income and minimizes their risk and management complexities. Accordingly, we consider a comprehensive set of variables, including expected profit per hectare, avoided risk, total labor avoidance, hired labor avoidance and direct cost avoided. Of this set of variables, three of them have relevance in explaining farmers' behaviour:

-Expected profit per hectare, measured by the gross variable margin:

$$z_1(x) = \sum_i x_i \pi_i \quad [20]$$

Where π_i is the gross variable margin per hectare of the crop i.

-Avoided risk, measured by the difference between the risk associated to the crop decision $\bar{x}$ leading to the maximum expected profit ($\bar{\sigma}$) and the risk associated to the alternative crop decision x ($\sigma\big(\pi(x)\big)$):

$$z_2(x) = \bar{\sigma} - \sigma\big(\pi(x)\big) \quad [21]$$

Where $\sigma\big(\pi(x)\big) = x^{\tau} VCV\big(\pi(x)\big)x$, being $VCV\big(\pi(x)\big)$ the variance and covariance matrix of the per hectare crop profits ($\pi(x)$) of the crop decision x.

-Hired labour avoidance, the second way to measure management complexities avoidance through the reluctance to use too much hired labour.

$$z_3(x) = \bar{H} - H(x) \quad [22]$$

Where similar to previous case $\mathrm{H(x)} = \sum_i \mathrm{x_i H_i}$ is the total hired labor used per hectare, being $\mathrm{H_i}$ the total hired labour required per hectare for a crop i, and $\overline{\mathrm{H}}$ is the hired labor required to implement the crop decision leading to the maximum expected profit.

As a result, our Cobb-Douglas Utility Function adapts the following form:

$$U(z_1, z_2, z_3) = z_1^{\alpha_1} z_2^{\alpha_2} z_3^{\alpha_3}; \quad \sum_{r=1}^{5} \alpha_r = 1 \qquad [22]$$

Where there are three unknown variables $(\alpha_r; r = 1, \dots 3)$. Following the methodology above, we estimate the values of the alpha coefficients for the Pinios RB. We also obtain the calibration errors. Results are displayed in Table 2:

Table 2. Alpha coefficients and calibration errors

Variable	α_1	α_2	α_3	e_f	e_τ	e_x	e
	0.947	0.007	0.046	1.83%	0.68%	1.67%	0.90%

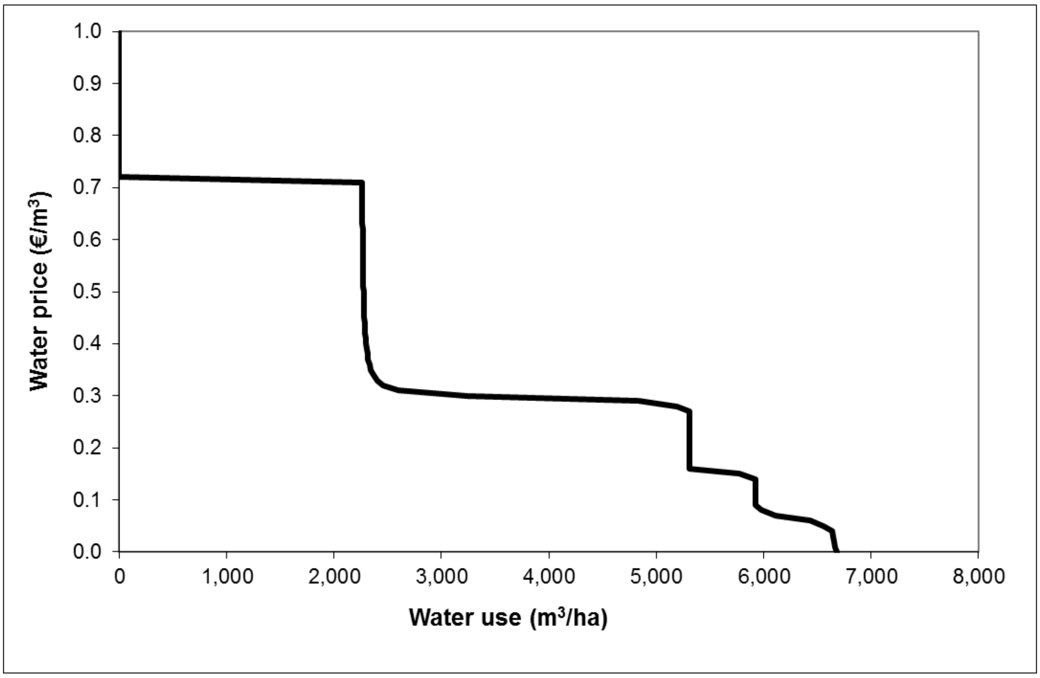
Source: Authors' elaboration

The most relevant attribute explaining the decisions of the farmers in the Pinios RB is the expected profit per ha (z_1), with an alpha coefficient of 0.947. Risk avoidance (0.007) and hired labor avoidance (0.046) have a marginal relevance. The mean calibration error is very low (0.9%), indicating that this model has a good potential to conducting policy analysis.

4.1.2 Simulation and results

Once the utility function has been defined, we implement a simulation in which we progressively increase water prices in the Pinios RB and we study farmers' responses in terms of water use, income and employment generation. We consider a price increase that ranges from 0 (baseline scenario) to 100 Eurocents/m3 (Δ 1 €/m3). Our first result is a water demand curve (Figure 1):

Figure 1. Water demand function in the Pinios RB (m3/ha)

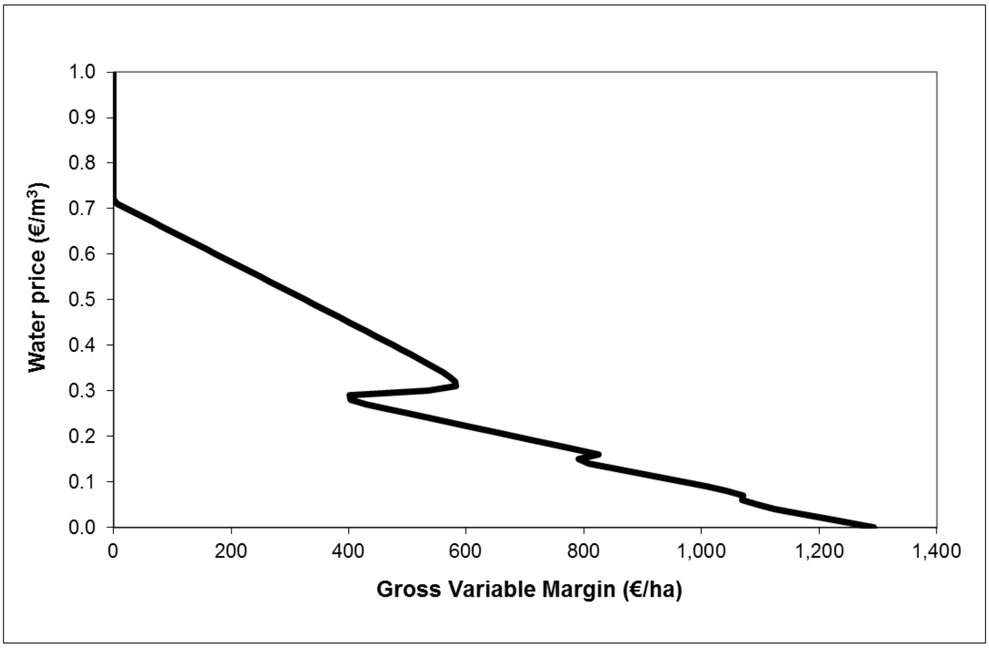


Source: Authors' elaboration

Figure 1 represents the average water demand in m3/ha for the whole basin. Water demand is inelastic up to a price increase of 0.05 €/m3. Above this price, the surface of maize, sugarbeet and alfalfa falls sharply and is replaced by rainfed agriculture and cotton, resulting in a rapid reduction of water use. The surface covered with maize, sugarbeet and alfalfa disappears when water prices reach 0.15 €/m3. Above this price, the only irrigated crop left, cotton, maintains its share of irrigated lands until prices reach 0.3 €/m3; at this point, the surface of cotton falls from 50% to 10%. When water price reaches 0.7 €/m3, there is no agricultural water demand since all the irrigated crops are replaced by rainfed crops.

The high sensibility of water demand to water prices is explained by the high exposure of the gross variable margin to changes in water prices. The gross variable margin of the farmers in the Pinios RB falls progressively and is finally reduced by over 70% after a price increase of 0.3 €/m3 (see Figure 2). Farmers react to this situation by relying on more labour intensive crops (cotton) instead of water intensive ones. As a result, higher prices increase employment in the agricultural sector, though this effect is reverted when the price increase reaches 0.3 €/m3 (Figure 3). At this the high prices of water make cotton no longer profitable and the surface of this crop, as well as the employment, fall.

Figure 2. Gross Variable Margin (€/ha) and water price increase (€/m3)



Source: Authors' elaboration

Figure 3. Employment generation (thousands of working days) and water price increase (€/m3)

Source: Authors' elaboration

5. Conclusions

The EU has promoted the adoption of volumetric water pricing as an effective means to reduce agricultural water demand. Although some authors support this position (Dinar and Subramanian, 1997), some others are rather sceptical and question the ability of the markets and in particular of water pricing to reduce water demand (Hellegers and Perry, 2006; Molle, 2001; Cornish et al., 2004). In fact, several case studies in different countries confirm that there is a large gap between the price and value of water for irrigation. As a result, a significant increase in water prices is necessary in order to balance water supply and demand (Hellegers and Perry, 2006).

This may imply significant costs in terms of income losses for the farmers, resulting in socio-economic problems.

Our results for the Pinios RB partially support these results. Water in this basin is free and a reduction in water use requires in any case that prices are fixed above 0.05 €/m3. Furthermore, a significant reduction in water use requires a price increase of at least 0.1 €/m3. This price level is well above the average water prices in other Southern European countries with higher income levels such as Spain (Maestu and Villar, 2007), and in the case of the Pinios RB results in a substantial reduction of farmers' income (measured by the gross variable margin) of more than 20%. It is important to note, though, the relevant increase of 10% in agricultural labour demand under this scenario. Price increases above this level, for example up to 0.3 €/m3, result in a reduction in the gross variable margin of more than 70% and also in reductions of the total labour.

Although there is still some room to use water pricing as an EPI to stabilize and even slightly reduce water use in the Pinios RB, this policy has to be used with extreme caution given the high exposure of farmers to price increases. In addition, our results are aggregated and do not show the impact among farmers; equity issues must be addressed if a water pricing policy is to be implemented.

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