Influence of crop-water production function on the expected performance of water conservation policies

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Highlights

Water conservation policies can exert three types of adaptive responses on irrigators: land reallocations from irrigated to rainfed agriculture (**super-extensive margin**), land reallocations towards less water intensive crops (**extensive margin**) and reductions in water use for irrigated crops or deficit irrigation (**intensive margin**)

This paper integrates a continuous agronomic production function into a positive **Mathematical Programming Model** with a multi-attribute utility function as objective of the optimization process (W-PMAUP model).

The economic and environmental performance are tested for three alternative water conservation policies namely **charges, quotas and buyback**.

A classic model (C-PMAUP) with expected values of yield in fixed proportion with water was ran to compare the results with the new model.

Results suggest that ignoring **intensive margin** adjustments leads to overestimation of the economic cost of charges, quotas and buyback

Study area

El Salobral-Los Llanos is an area of 420 km² in the southeast part of the Mancha Oriental System, central Spain. It has a Mesomediterranean continental climate with dry summer and the most rain occurs in spring and fall. The principal crops considered occupy the 70% of total agricultural area.

Crop-water production function

Following agronomic literature and Peña-Haro et al., (2010), a quadratic water production function was obtained and calibrated for the study area. Peña-Haro et al., (2014) estimate the functions depending on water application.

The functions are obtained for the 6 principal crops: wheat, barley, corn, garlic, onion (Peña-Haro et al., 2014) and almond (ITAP, 2004). Both, A yield and a cost function were used in the model:

$$YLD_i = a\,w^2 + b\,w + c \qquad Cost_i = d\,YLD_i + e$$

Both functions have a rainfed term that could be only positive in the case of the cost function ($e > 0$), but also negative in the case of yield function (for the crops that could not be cultivated as rainfed).

These equations are used in the profit attribute evaluation in the W-PMAUP model, while the maximum expected values are used in the C-PMAUP.

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Models and calibration

The **PMAUP models** follow a mathematical formulation with a Cobb-Douglas utility function:

$$\max_x U = U(\boldsymbol{Z}(\boldsymbol{X},\boldsymbol{W})) = Z_1^{\alpha_1}(\boldsymbol{X},\boldsymbol{W})\, Z_2^{\alpha_2}(\boldsymbol{X},\boldsymbol{W})\, Z_3^{\alpha_3}(\boldsymbol{X},\boldsymbol{W})$$

s.t.

$$\sum_{i=1}^{n} x_i = 1 \qquad 0 \le x_i \le 1$$

$$\sum_{i=1}^{n} w_i = \mathrm{WA} \qquad 0 \le w_i \le \mathrm{WA}$$

$$\boldsymbol{X},\boldsymbol{W} \in F \in R^n$$

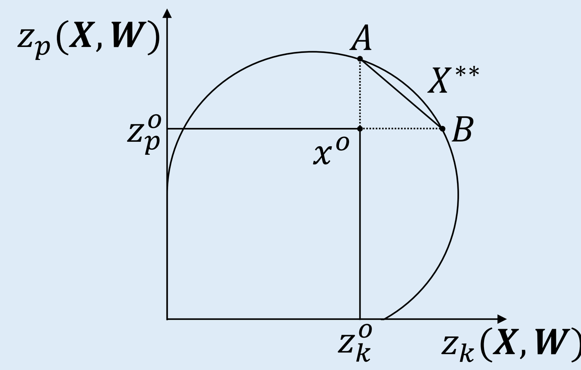
$$\boldsymbol{Z}(\boldsymbol{X},\boldsymbol{W}) \in R^3$$

Where X is the crop portfolio vector, W is the water allocation vector, WA represents the average water availability per hectare, and $\boldsymbol{Z}(\boldsymbol{X},\boldsymbol{W})$ is the vector of utility-relevant attributes. The optimization process is constrained to conform with the domain F.

Z_1 indicate the expected profit, Z_2 the risk avoided and Z_3 the labor avoided; the three attribute are only function of land in the classic model.

Calibration

The model follows the calibration of Gutíerrez-Martin and Gómez (2011), named projection method



In order to approximate the efficient frontier, the hyperplane passing through A and B is used to approximate the Marginal Rate of Transformation (MRT_{kp}) that is equalized to the Marginal Rate of Substitution (MRS_{kp}) to obtain the slope of the indifference curve.

Results shown in the following table, reveal an agent that consider profit and risk as relevant attributes; the error is considered low, being less than 10%.

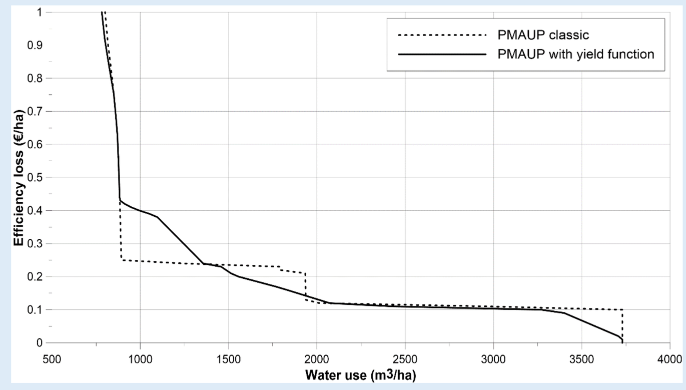
Attribute (z_p)	z_1	z_2	z_3	e_m
Parameter value (α_p)	0.81	0.19	0.00	2.42%

Conclusion

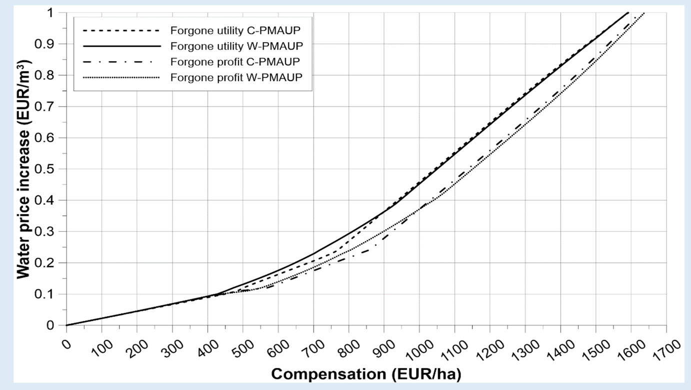
The W-PMAUP displays a superior performance than the C-PMAUP model setting, particularly the inelastic responses in the initial (and middle) stretches of the C-PMAUP water use function (consistent with findings in the literature on water charges in water scarce areas) appear softened in the W-PMAUP, suggesting a more effective contribution of water charges towards water conservation. Ignoring intensive margin adjustments also tends to overestimate the economic impact of water conservation policies: charging, quotas and buyback policies display a higher foregone profit and utility.

Simulations results

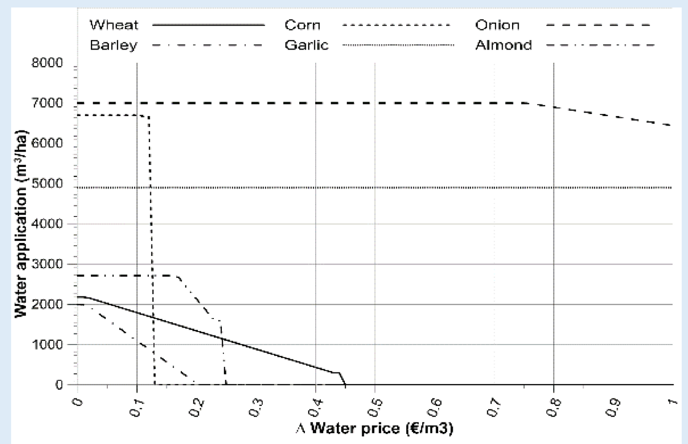
Water charges simulation: water price is increased up to 1 EUR/m³ in 100 simulations. After every increase the agent could reallocate his land and water (only W-PMAUP) to optimize his utility function.



The classic model is characterized by a jumpy behavior with marked inelastic stretches that disappear when intensive margin adaptation is included

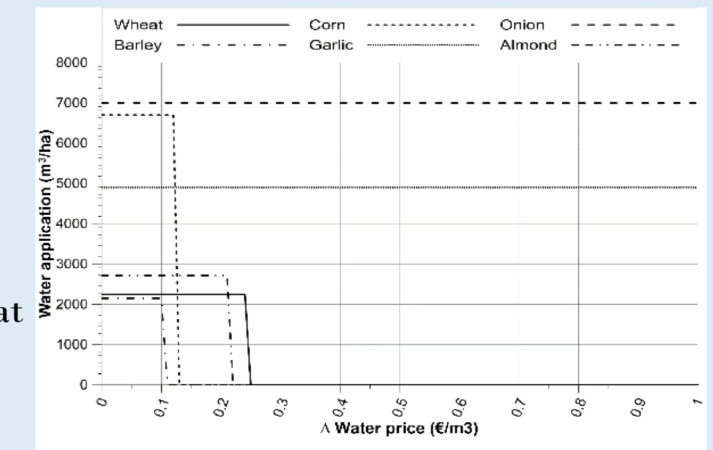


Forgone utility and profit measure the economic impact in term of the amount of money the irrigator would need to achieve his initial profit/utility.



W-PMAUP water application per crop.

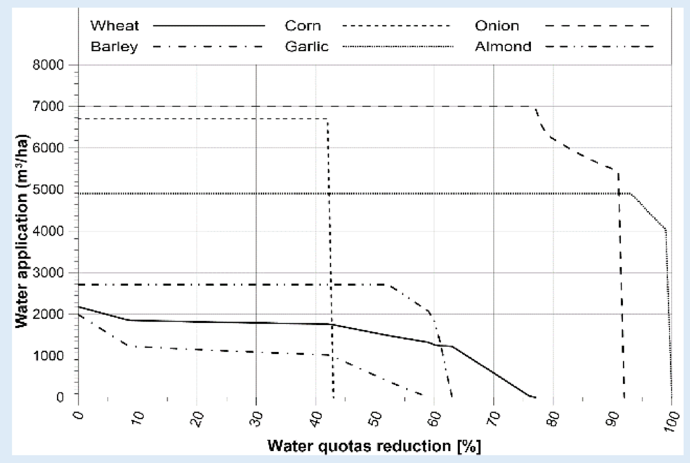
Deficit irrigation is applied in 4 crops, but in garlic (the most profitable crop) and corn (high yield elasticity to water application).



C-PMAUP water application per crop.

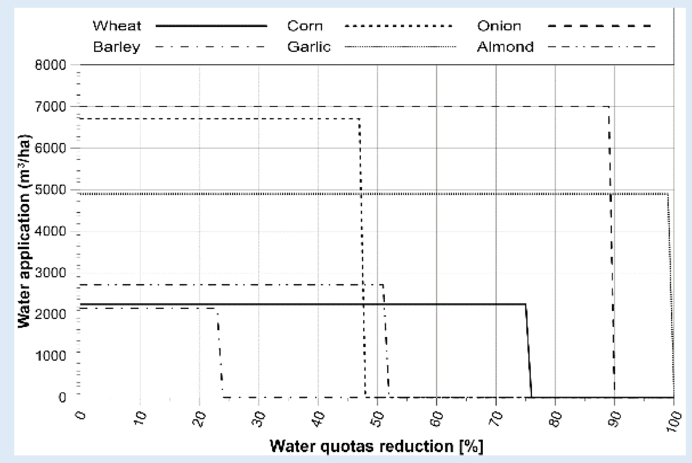
Agents are constrained to apply water in fixed proportions to land, meaning that intensive margin adjustment are not possible.

Water quotas and buyback simulation: the water allocation constraint was strengthened from 0% to 100% to assess crop portfolio and water allocation responses.



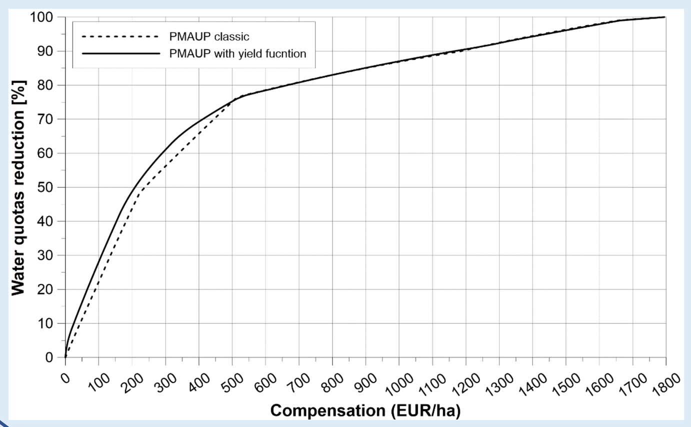
W-PMAUP water application per crop.

Since water allotments are reduced by up to 100%, all crops with the exception of corn, including highly profitable irrigated crops, experience deficit irrigation.



C-PMAUP water application per crop.

Because the impossibility of intensive margin adjustment, substitution with rainfed crops starts earlier tan with W-PMAUP.



The figure shows the economic impact of water allocation restrictions in terms of the monetized utility loss and represents the minimum amount of money irrigators would be willing to accept for trading their right to use water.

Literature

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