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The Microeconomics of Water Demand under Deficit Irrigation: A case study in southern Spain.

Alfonso Exposito, University of Seville (Spain)
Julio Berbel, University of Cordoba (Spain)

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Introduction

- Analysis of the microeconomics of deficit irrigation (DI) that may significantly impact **irrigation water demand** on its two fundamental variables, **water use** (applied irrigation dose) and **price** (elasticity to water cost).

- Our research focuses on the **technique of deficit irrigation** as defined by consisting of the supply of irrigation water below the total irrigation requirements throughout the crop cycle (Molden et al., 2010).

Introduction

- A majority of water models are based on the assumption that there is limited availability of irrigated land, but water supply is unlimited (*i.e.*, it significantly exceeds crop needs).

- Berbel and Mateos (2014) expand the model developed by English (1990) to account for deficit irrigation under a water constrained supply. This model will serve us to analyze the behavior among our sample of farmers when they decide the water dose applied to their crops.

Introduction: Hypotheses

- Farmers maximize returns for the water considering water volume as fixed and land as a variable input, instead of the conventional economic optimum of maximum returns for the land with water as the variable input and land as the limited factor

→ **Water-use decision making**.

- Secondly, in areas where farmers adopt DI as a predominant strategy in response to water scarcity, the structure of the water demand function is also impacted in its elasticity with respect to price, leading to an ineffectiveness of water pricing at curtailing water demand, unless a disproportionate high threshold price is reached → **Water-price decision making**.

Implications DI on water-use DM

A majority of the water use models are based on the assumption that there is limited availability of irrigated land, but water supply is unlimited (*i.e.*, it significantly exceeds crop needs). Accordingly, water is treated as a variable input and land as a constrained resource. This assumption implies that farmers displaying rational economic behavior should maximize the following profit equation:

$$Z = P_y Y - P_w W - C$$

where Z denotes profit, P_y is the price of the crop, P_w is the price of water, and C represents fixed costs.

English and Raja (1996) illustrate this model with an example based on a quadratic water response production and cost functions, such as those represented below:

$$Y(w) = a_1 + b_1 W + c_1 W^2$$

$$C(w) = a_2 + b_2 W$$

Implications DI on water-use DM

Berbel and Mateos (2014) expanded the model developed by English (1990) to account for deficit irrigation, efficiency changes and the situation in which land is not a binding constraint and water is a limiting factor. Thus, farmers who behave rationally in an economic sense seek to maximize total net income, being A the irrigated surface:

$$Z \cdot A = A \cdot \left(P_y Y - P_w W - C\right)$$

Implications DI on water-use DM

The solution to this optimization problem represents the maximum return to land and is determined by the value of water dose "W_l" given by:

$$W_l = \frac{b_2 - P_y b_1}{2\,P_y c_1}$$

The solution to the second problem posed in Equation (2) considers water as a limited input while land becomes a freely variable input. This alternative model gives the maximum return to water (dose "W_w"):

$$W_w = \left(\frac{P_y a_1 - a_2}{P_y c_1}\right)^{1/2}$$

Finally, it is relevant to the microeconomic analysis of irrigation to determine the maximum yield solution. This straightforward solution is widely used to determine the maximum irrigation requirements; by solving the equation system the maximum yield is found at the point "W_m" represented by:

$$W_m = \frac{-b_1}{2\,c_1}$$

Implications DI on water-price DM

- Bernardo and Whittlesey (1989), Ogg and Gollehon (1989), Dinar and Letey (1996) and Varela-Ortega et al. (1998) are good examples of attempts to model responsiveness to water pricing among farmers under restricted water supply (demand inelasticity).

- Nevertheless, it is still debatable whether or not water pricing is an effective measure in water demand management (De Fraiture & Perry 2007). Several studies claim that irrigation water demand is inelastic below a threshold price, and elastic beyond it (i.e. Perry 2001; Ray 2002). Thus, considerable price increases would be required to produce a reduction in demand, and such increases may involve important political considerations.

Implications DI on water-price DM

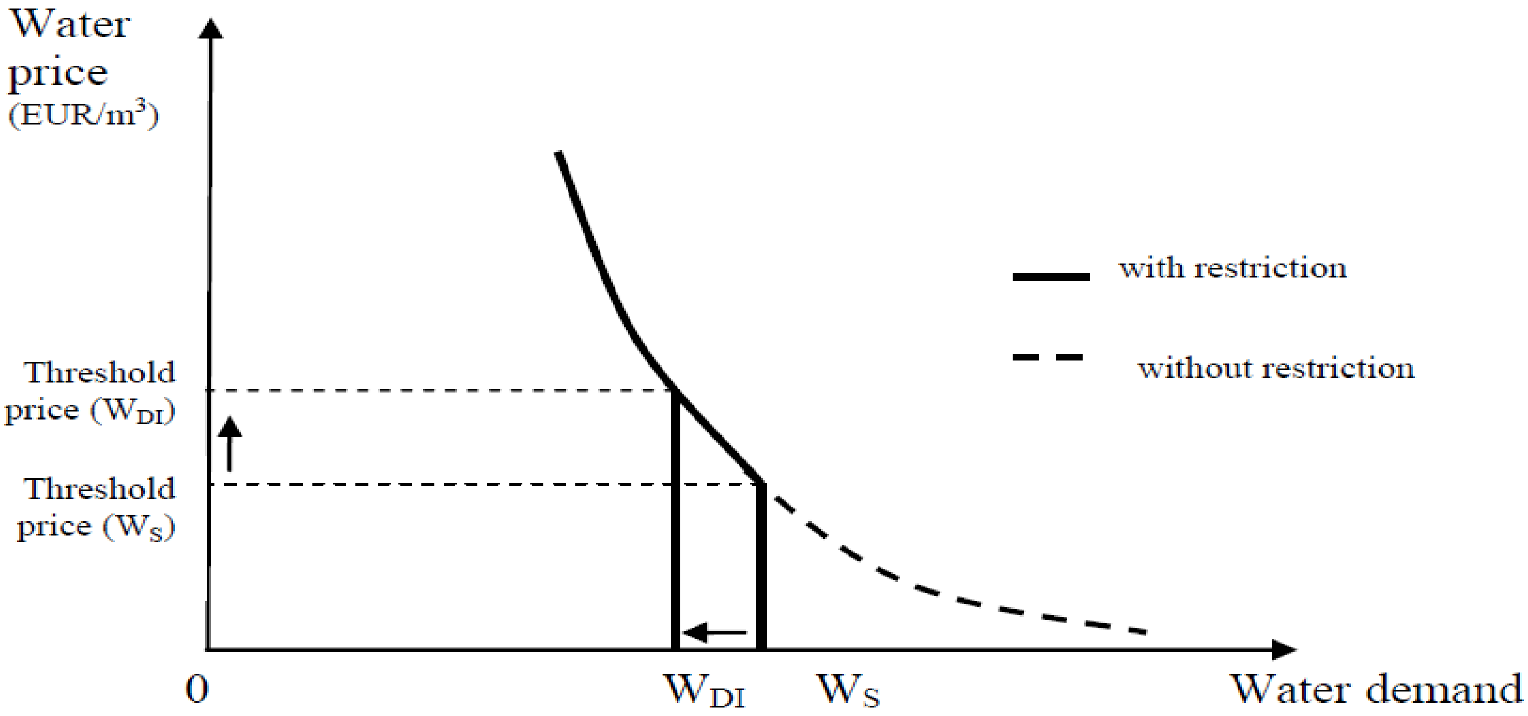

Figure 1. Water demand under restricted supply (W_S) and deficit irrigation (W_{DI}).

Adapted from De Fraiture & Perry (2007)

Case Study

- Based on farmers' subjective beliefs about the water-yield relationship in irrigated intensive olive groves in Andalusia (southern Spain).
- Guadalquivir River Basin, longest river in southern Spain: 650 km length, 58,000 km^2, population of 4.1 million (cities of Seville, Cordoba and Granada).
- Mediterranean climate with an uneven rainfall distribution (630 mm) and an average annual temperature of 16.8 °C. Annual renewable resources are estimated at 7.1×10^9 m^3 for surface waters and 2.6×10^9 m^3 for groundwater.
- Agriculture is the top consumer: 87% of the total.
- Olive groves represent the main crop in the basin.
- New irrigation technologies have allowed farmers to significantly increase tree densities: intensive groves (between 250 and 300 trees per hectare).

Case Study: Survey

Table 1. Basic descriptive parameters.

	Area (ha)	Density (trees/ha)	Age (years)	Irrigation Rights (m^3/ha)	Yield (kg/ha)	Irrigation Dose (m^3/ha)
Average	40	283	15	2,723	6,382	1,028
St. Dev.	64	80	6	1,846	2,344	388

- Conducted in spring 2014 with information regarding yield and irrigation doses per ha, among other data, in the period 2010–2013.
- 99 observations (farmers): 48 valid.
- Water use represents 38% of water rights (irrigation dose/water rights = 1,028/2,723). Indication of the dominant DI strategy studied in our research.
- Potential evapotranspiration (PET) in the year of the survey was estimated at 492 mm for the intensive olives.

1st Hypothesis: Results

The average applied dose is close to the irrigation dose which maximizes returns for water when water is the limited resource (W_w). A simple *t*-test of significance between the mean values of the data distributions for W_o and W_u, and that obtained from the estimated distribution of variable W_w, show that peer data distributions W_o and W_w, as well as the peer W_u and W_w, have similar distributions with statistically equal mean values.

Table 2. Solutions to the microeconomic model and observed behavior.

	Analytical Solution			**Survey**	
m³/ha	**Max. Yield (W_m)**	**Max. Return to Land (Water Free) (W_l)**	**Max. Return to Water (Land Free) (W_w)**	**Usual DI (W_u)**	**Avg. Dose 2010–2013 (W_o)**
Maximum	6,759	6,566	2,731	2,500	2,500
Minimum	538	613	248	600	600
Median	3,060	2,802	1,013	1,450	1,042
Average	3,178	3,005	1,163[1,2]	1,357[1]	1,103[2]
St. Dev.	*1,391*	*1,298*	*571*	*425*	*350*

[1] At a 95% confidence interval, the *t*-test for the difference between means determines that Mean W_u=Mean W_w; [2] At a 95% confidence interval, the *t*-test for the difference between means determines that Mean W_o=Mean W_w.

2nd Hypothesis: Results

Table 3 shows descriptive statistics of the elicited threshold price levels given by the estimated marginal product value of water at the usual irrigation dose applied by each farmer, together with information regarding the current water cost. The average estimated marginal product value associated with the average applied water dose in our sample shows that the threshold price would be around 1.2 EUR/m^3, which is 10 times the current average water cost paid by our sample of farmers (0.11 EUR/m^3).

Table 3. Water cost and elicited threshold price.

	Water cost (EUR/m^3)	**Applied Water dose (m^3/ha)**	**Threshold Price (EUR/m^3)**
Maximum	0.30	2,500	4.68
Minimum	0.05	600	0.20
Median	0.08	1,042	1.03
Average	0.11	1,103	1.22
St. Dev.	*0.09*	*350*	0.88

Concluding remarks

- Our research is focused on a specific area and crop (what clearly implies a limitation of this study).
- Nevertheless, it suggests that a general use of DI is a technique that allows the farmer to seek maximum return to water, taking irrigation decisions with water as limiting factor and impacting the price-elasticity of water demand till a disproportionate threshold price level (relative to current water costs).
- Water pricing policy loses effectiveness in areas characterized by widespread of DI techniques, as is the case of the Guadalquivir river basin in southern Spain.
- The extensive adoption of this technique will have serious consequences for the river basin management, requiring further research that is beyond the scope of this preliminary analysis.

THANK YOU FOR YOUR ATTENTION

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