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An extended PMP model to analyze farmers' adoption of deficit irrigation under environmental payments

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Abstract

The growing policy pressure to reduce water use could lead to the introduction of environmental payments granted on the basis of the amount of water farmers save. This paper proposes an extension of the PMP Röhm and Dabbert approach in order to consider deficit irrigation crop techniques which are not observed in the reference period. The proposed methodology is applied to an Italian irrigated area to evaluate the likely impact of such environmental payments on water use, cropping patterns, adoption of deficit irrigation techniques and economic results on farms. The analysis shows that the considered payments induce farmers to reduce water use, to adopt deficit irrigation techniques and increase economic results. This latter result occurs because the payments counterbalance the negative impact caused by the reduction of water use.

Additional key words: agro-environmental payments; deficit irrigation techniques; farmers' behaviour; positive mathematical programming; water saving policies.

Resumen

Un modelo de PMP extendido para analizar la adopción de técnicas de riego deficitario bajo pagos ambientales

La creciente presión de la opinión pública para reducir el uso del agua podría llevar a introducir pagos medioambientales basados en la cantidad de agua que el agricultor ahorra. Este artículo propone una extensión del modelo PMP Röhm y Dabbert para incluir en este varias técnicas de déficit de riego, las cuales no han sido observadas en el periodo de referencia. Se ha aplicado la metodología propuesta a un area irrigada de Italia, para evaluar el posible impacto de estos pagos ambientales en el uso de agua, modelos de cultivo, adopción de técnicas de déficit de riego, así como en los resultados económicos. El análisis muestra que los pagos considerados inducen a los agricultores a reducir el uso del agua, a adoptar técnicas de déficit de riego y aumentan los resultados económicos. Este último resultado ocurre porque los pagos superan el impacto negativo causado por la reducción del uso del agua.

Palabras clave adicionales: comportamento de los agricultores; pagos agro-ambientales; políticas de ahorro de agua; programación matemática positiva; técnicas de déficit de riego.

Introduction

There is a growing policy interest in reducing water use in agriculture when this generates sufficiently large environmental benefits. The application of the EU Water Framework Directive (WFD) has fostered an increasing number of economic analyses to investigate farmers' behavior by means of mathematical programming techniques (Berbel and Gómez-Limón, 2000; Garrido *et al*., 2003; Bartolini *et al*., 2005; Pujol *et al*., 2006) including Positive Mathematical Programming (PMP) models (Blanco *et al*., 2004; Iglesias and Blanco, 2008; Cortignani and Severini, 2009). These models have been used to evaluate the impact of likely increases of water payments that the application of the WFD is expected to cause on groups of farms in terms of their cropping patterns, water use and economic results.

Despite their increasing popularity in economic analysis, traditional PMP models generally fail to include activities that were not observed in the reference period.

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Abbreviations used: CAP (Common Agricultural Policy); DI (deficit irrigation); EU (European Union); IB (irrigation board); MTR (mid-term review of the CAP); PMP (positive mathematical programming); UAA (utilized agricultural area); WFD (Water Framework Directive).

This can be limiting in the sector of water policy because, under the pressure of new market and policy conditions, farmers may adjust not only their cropping patterns but also the amount of water per hectare they use.

Irrigated agriculture in Europe is currently adapting to new environmental and policy conditions. On one hand, water available for irrigation is expected to decrease in many areas of the world because climate change is causing an increase in temperatures and a decrease in rainfall (Farrè and Faci, 2009) and because there is a growing competition for water use generated by non-farm users and by the growing demand for environmental services (Blanco *et al*., 2004). This is generating a growing policy pressure to increase water costs and to reduce water use also in agriculture. The WFD, in order to promote sustainable water use based on a long-term protection of available water resources, asks Member States to take account of the principle of recovery of the costs of water services, including environmental and resource costs. The application of this principle is expected to increase the water cost Italian farmers are going to pay in the future. This is because currently Italian farmers are charged by Irrigation Boards only for the operational variable costs (*i.e.* not the infrastructure fixed costs) for the service of delivering the water to the farmers.

On the other hand, the Common Agricultural Policy (CAP) is under scrutiny to develop a policy for the years following 2013 that generates larger social benefits and justifies public spending in a better way. The recent *Health Check* reform of the CAP has channeled financial resources to the so called "new Challenges" one of which specifically refers to water management in agriculture (EC, 2009b). Because of the growing emphasis on this objective and the financial resources available for this area to be used also in Rural Development Policies, it is likely that agro-environmental policy could accommodate for some payments granted on the basis of the amount of water farmers save. Indeed, agro-environmental payments have been traditionally judged as a useful tool to promote the production of environmental services and, in the meantime, to support farm income.

New techniques with low irrigation water requirements could play a key role in this scenario. In particular, Deficit Irrigation (DI) is said to provide a way to reduce water use in agriculture because it allows a crop to sustain some degree of water deficit in order to better use the overall available water, to reduce irrigation costs and, potentially, to increase farm income (Fereres and Soriano, 2007). The potential benefits of introducing DI derive from three factors: increased irrigation efficiency, reduced irrigation and water opportunity costs (English and Raja, 1996).

As farmers have the option of deciding whether or not to adopt DI, it is important for the research agenda to focus on models that represent farmers' behavior under the new expected conditions. In fact, this kind of analysis sheds light on whether DI can satisfy water saving objectives with limited negative implications on farmers' income.

In recent years, PMP has been increasingly used in farm-level economic analyses. This approach requires a relatively limited amount of data and allows calibrating models perfectly to the reference period on the basis of the assumptions discussed below. However, because PMP models generally fail to represent activities that were not observed in the reference period, there have been some attempts to include these activities to allow for more flexibility in model responses (Paris and Arfini, 2000; Blanco *et al*., 2008; Iglesias and Blanco, 2008). Not taking these activities into consideration is a shortcoming in the specific field of irrigation analysis because, when for example water availability decreases or water costs increase, farmers may find it convenient to introduce DI techniques that were not profitable previously and were not observed under baseline conditions (Lezoche and Severini, 2007).

This paper proposes an extension of the PMP (Röhm and Dabbert, 2003) approach in order to include deficit irrigation (DI) crop techniques not observed during the reference period in the models. These alternative techniques, identified by means of a crop growth model developed by the FAO (Clarke *et al*., 1998), are included by using a method recently proposed by Cortignani and Severini (2009). The proposed methodology is applied to an irrigated area of Italy to evaluate the likely impact of environmental payments granted on the basis of the amount of water farmers save, cropping patterns, adoption of deficit irrigation techniques and farm economic results.

Material and methods

PMP: *standard* and Röhm and Dabbert approaches

The PMP methodology, developed to calibrate agricultural supply models (Arfini and Paris, 1995;

Howitt, 1995; Heckelei and Britz, 2005), assumes a profit-maximizing equilibrium in the reference period. It recovers additional information from observed activity levels in order to specify a non-linear objective function so that the resulting non-linear model reproduces the observed situation in the base year.

The *standard* approach (Arfini and Paris, 1995) involves three steps: 1) Specification of a linear programming model bound to the observed activity levels by calibration constraints, in order to obtain the additional marginal variable costs for these activities; 2) Estimation of a quadratic variable cost function assumed to capture all farming conditions not modeled in an explicit way; and 3) The formulation of a quadratic programming model including the variable cost function in the objective function. This model reproduces the behavior observed in the base year exactly and can be used to perform simulations on several parameters of the model, including product and factor prices, subsidies and resource availability. The variable cost function is assumed to be quadratic because this form is relatively easy to work with and has the desirable property of increasing marginal cost functions for each activity, apart from the marginal (least profitable) activity.

Denoting the crops by *j*, the quadratic programming model can be compactly written as:

$$\begin{aligned} \text{Max } Z &= \sum_j \left(r_j - AC_j(x_j)\right)x_j \\ s.t.\ &\textstyle\sum_j a_{i,j}\, x_j \le b_i \\ &x_j \ge 0 \end{aligned} \qquad [1]$$

where Z denotes the objective function value; x_j represents the production activity levels (hectares allocated to crop j); r_j denotes average revenue per unit of activity; $a_{i,j}$ represents the scalar element of a matrix of coefficients in the resource/policy constraints (index i); b_i is the vector of available resource quantities; $AC_j(x_j)$ denotes average variable cost function per unit of activity and has the following form:

$$AC_j\left(x_j\right) = \alpha_j + \frac{1}{2}\beta_j x_j \qquad [2]$$

where α and β are parameters to be estimated.

Multiple sets of cost function parameters satisfy the first order conditions of the problem [1]. One of the options for recovering these parameters is the following (Arfini and Paris, 1995):

$$\alpha_j = c_j;\ \beta_j = \frac{\mu_j}{x_j^0} \qquad [3]$$

where c_j are the observed accounting costs and μ_j are the additional marginal variable costs. These latter values are recovered by means of the following calibration constraints included in the linear programming model of the first step of PMP:

$$x_j \le x_j^0\left(1+\varepsilon\right) \quad \left[\mu_j\right] \qquad [4]$$

where x^0_j are the observed variable levels and ε is a small positive number (Howitt, 1995).

In the *standard* approach, the parameters of the cost function are recovered for each land-use activity separately. In this way, different production technologies for the same crop (variants) are taken as separate activities. Therefore, it is not considered that a large substitution among these variants could occur in the simulation phase, because they have similar technical-agronomic characteristics. Indeed, variants generally refer to different ways of producing the same crop product and they differ only in terms of the amount of used production factors (*e.g.* amount of fertilizers and water, irrigation technologies, crop protection technologies) and yield. Therefore, farmers can be expected to adjust cropping technologies more easily (*i.e.* switching from one variant to another of the same crop) than cropping mix (*i.e.* switching from one crop to another).

Röhm and Dabbert (2003) propose a different modeling approach to account for the fact that the elasticity of substitution is expected to be higher between variants of the same crops than between different crops. Denoting the crops by *j* and the variants by *v*, the quadratic programming model can be written as:

$$\begin{aligned} \text{Max } Z &= \sum_j \sum_v \left(r_{j,v} - AC_{j,v}(x_{j,v})\right)x_{j,v} \\ s.t.\ &\textstyle\sum_j \sum_v a_{i,j,v}\ x_{j,v} \le b_i \\ &x_{j,v} \ge 0 \end{aligned} \qquad [5]$$

where average variable costs per unit of activity *($AC_{j,v}$)* are defined as:

$$AC_{j,v}\left(x_{j,v}\right) = \alpha_{j,v} + \frac{1}{2}\ \beta_{j,v}\ x_{j,v} + \frac{1}{2}\gamma_j\ \textstyle\sum_v x_{j,v} \qquad [6]$$

The Röhm and Dabbert approach (2003) introduces an additional slope parameter (γ) not included in [2] which is common to all variants of the same crop.

Therefore, there are two sets of slope parameters, one for each crop (γ) and another for each variant of the same crop (β).

As for the *standard* approach, multiple sets of cost function parameters satisfy the first order conditions. One option to recover these parameters is[1]:

$$\alpha_{j,v} = c_{j,v}\ ;\ \beta_{j,v} = \frac{\mu_{j,v}}{x^0_{j,v}}\ ;\ \gamma_j = \frac{\mu_j}{\sum_v x^0_{j,v}} \qquad [7]$$

where $c_{j,v}$ are the accounting costs. The other parameters can be recovered on the basis of the results of the original linear problem of the first step of PMP with two sets of additional calibration constraints:

$$\sum_v x_{j,v} \le \sum_v x^0_{j,v}\left(1+\varepsilon_1\right) \quad \left[\mu_j\right] \qquad [8]$$

$$x_{j,v} \le x^0_{j,v}\left(1+\varepsilon_2\right) \quad \left[\mu_{j,v}\right] \qquad [9]$$

where ε_1 and ε_2 are small positive numbers ($\varepsilon_1 < \varepsilon_2$); μ_j are the additional marginal variable costs associated with crops; and $\mu_{j,v}$ are the additional marginal variable costs associated with crop variants.

In our analysis, we recover the cost function parameters under quite unfavorable conditions. We have only one observation (*i.e.* the vector of cropping patterns for each sub-area), a set of yield and economic parameters to estimate the average gross margins for each cropping activity, estimates of irrigation water requirement for each crop and no prior information other than land rental value. This latter is used to obtain an increasing marginal cost function also for the marginal activity using the approach developed by Gohin and Chantreuil (1999). Indeed, in the *standard* approach the μ dual value referring to the marginal activity vanishes and consequently the β slope coefficient is equal to zero. Setting the dual value for the land constraint equal to the observed land rental value, the μ dual value for the marginal activity becomes greater than zero and it is possible to recover a non-zero β slope coefficient also for this activity.

The proposed PMP approach

The method proposed here is an extension of the Röhm and Dabbert approach (2003) with the cost parameter defined according to the calibration method of Arfini and Paris (1995). This allows for the consideration of activities that are not present in the reference year.

For some of the observed irrigated crops, there are different irrigation techniques (crop variants *v*): full and DI techniques. The first is observed in the reference period while the DI techniques are not.

In contrast to [8] and [9], the calibration constraints are specified as:

$$\sum_v x_{j,v} \le \sum_v x^0_{j,v}\left(1+\varepsilon_1\right)+\varepsilon_3 \quad \left[\mu_j\right] \qquad [10]$$

$$x_{j,v} \le x^0_{j,v}\left(1+\varepsilon_2\right)+\varepsilon_3 \quad \left[\mu_{j,v}\right] \qquad [11]$$

where ε_3 is a sufficiently small positive number ($\varepsilon_1 < \varepsilon_2 < \varepsilon_3$). In fact, considering that some variants are equal to zero, an additive small positive number (ε_3) must be specified for the variants not observed (in this case the DI techniques) in order to recover non zero dual values (μ) in all cases.

Having recovered the additional marginal variable cost parameters, the average cost functions are specified as:

$$AC_{j,v}\left(x_{j,v}\right) = \alpha_{j,v} + \frac{1}{2}\beta_{j,v}\, x_{j,v} + \frac{1}{2}\gamma_j \sum_v x_{j,v} + \vartheta_{j,v} \qquad [12]$$

The parameters of the cost function are recovered as:

$$\alpha_{j,v} = c_{j,v}\ ;\ \beta_{j,v} = \frac{\mu_{j,v}}{\sum_v x^0_{j,v}}\ ;$$
$$\gamma_j = \frac{\mu_j}{\sum_v x^0_{j,v}}\ ;\ \vartheta_{j,v} = \mu_{j,v}\left(1 - \frac{x^0_{j,v}}{\sum_v x^0_{j,v}}\right) \qquad [13]$$

where $\vartheta_{j,v}$ are linear cost parameters that consider the relative weight of variant *v* within the crop *j*. This method of recovering the cost parameters satisfies the first order conditions of the considered problem. The parameter $\vartheta_{j,v}$ is relatively large when the variant is cultivated on a limited share of the whole crop *j* area.

Also Paris and Arfini (2000), Blanco *et al*. (2008) and Iglesias and Blanco (2008) use another linear parameter to capture differences between single farms or site-specific characteristics by inference from data for similar farms or farms in the same location.

However, in contrast with the original approach, our method allows the recovery of a β slope coefficient

[1] The expressions [7] are an extension of the calibration method of Arfini and Paris (1995) considering the Röhm and Dabbert approach (2003).

even when the variant is not observed in the reference period. In particular, parameters β are calculated by means of the whole crop *j* area and, as a result, they are not influenced by the area of each specific variant. This prevents the variants of the same crops having very different slopes when they are cultivated at different levels. This is a desirable property because, as variants of the same crop, they have similar technical – agronomic characteristics and their marginal costs are expected to be relatively similar. Further differences between variants are captured by the linear parameter of the cost function ($\vartheta_{j,v}$) that does not depend on the production level. This occurs because $\vartheta_{j,v}$ considers the relative importance of variant *v* within the crop *j* and the recovered $\beta_{j,v}$ slope takes into account the specific economic characteristics of the considered variant.

The empirical model

The empirical model has been developed using data from the agricultural area served by the Irrigation Board (IB) "Maremma Etrusca" located in Central Italy, about 80 kms north of Rome. There are approximately 1,000 farms in this area covering about 8,000 ha of land, more than one-third of which is irrigated (Table 1). Water is obtained from a river that originates from lake Bolsena where considerable recreational activities occur during the summer (*e.g.* swimming, boating and fishing). The water outflow is reduced in this period in those years characterized by limited rain flow to ensure that the water level of the lake is kept high enough to allow for these activities. When this occurs, water availability for downstream farmers becomes limited during the summer. Water availability for the farming sector is expected to decrease in the future due to a decline in the importance of farming and the growing demand for water for the tourism sector.

Water cost is charged to farmers by multiplying water use by an average unitary water distribution cost coefficient (€ m^{-3}) (Table 1). The IB calculates it at the end of the irrigation season by dividing water distribution cost by the amount of water distributed in each sub-area. This value is very low because it accounts only for the variable cost of water distribution incurred by the IB. It does not account for the financial cost of the infrastructures managed by the IB, nor for the opportunity and environmental costs of this resource. This clearly conflicts with the aim of the WFD that requires

Table 1. Cropping patterns, economic data and main characteristics of the study area and sub-areas L1, L2 and L3[1] (2004)

Cropping activity	Observed activity levels (ha)				Unitary irrigation requirements (m^3 ha^{-1})	Prices (€ ton^{-1})	Yield (ton ha^{-1})	Variable specific costs	
	L1	L2	L3	Total				Water (€ ha^{-1})	Other factors[2] (€ ha^{-1})
Durum wheat	1,421	1,351	1,934	4,706	–	140	4.0	–	601
Soft wheat	39	–	–	39	–	120	5.0	–	520
Barley	–	35	–	35	–	120	4.1	–	450
Maize	38	37	99	174	3,430	170	11.0	313	1,132
Asparagus	4	8	8	20	2,367	2,200	3.5	225	1,600
Artichokes	21	30	57	108	1,685	979	7.0	154	1,511
Cabbage	6	1	1	8	790	250	14.0	72	1,253
Sugar beets	9	26	11	46	2,609	43	70.0	238	1,315
Tomatoes	193	384	437	1,014	2,720	47	80.0	249	2,680
Melons	69	60	76	205	2,200	250	25.0	201	2,152
Watermelons	113	117	100	330	2,460	170	35.5	225	1,670
Fennel	89	150	186	425	2,050	350	29.0	187	1,256
Other crops	319	171	397	887	–	–	–	–	–
Utilized agricultural area (ha)	2,321	2,370	3,306	7,997					
Irrigated land (ha)	578	829	1,005	2,412					
Water use (1000 m^3)	1,416	2,056	2,553	6,026					
Average water cost (€ m^{-3})	0.07	0.12	0.12						

[1] The irrigation board delivers water using three non-fully connected irrigation systems, which we distinguish as sub-areas L1, L2 and L3. Each sub-area is represented as a separate entity made up of the sum of all farms located in that section of the study area. [2] Excluding labour.

charging water costs accounting also for these latter cost categories. This makes the application of the principles of the WFD to likely increase the unitary water costs farmers will face in the future.

The IB delivers water using three non-fully connected irrigation systems, which we distinguish as sub-areas L1, L2 and L3. These sub-areas are similar in terms of soil quality, farm size and production technologies. Data on cropped area, input use, variable costs per activity, expected product prices and yields by crop, water charges, irrigated area, water availability and agricultural policy subsidies and constraints were collected and used in previous research (Cortignani and Severini, 2004; Lezoche and Severini, 2007; Blanco *et al*., 2008; Cortignani and Severini, 2009). Each sub-area is represented in the model as a separate entity made up of the sum of all farms located in that section of the study area.

We calibrated the model to the pre-reform situation using 2004 cropland allocation data for 26 crops. Specifically, most of the land is allocated to durum wheat, but horticultural crops are also important, especially tomatoes for processing.

The structural constraints of the model refer to land and water. Land constraints account for both the total land and land used for permanent crops. Water constraints refer to the balance between crop requirements and water availability: these constraints apply to the annual balance and to three main irrigation periods: spring, summer and autumn.

Given the low cost of water and the large annual availability of water, the amount of water distributed to farmers is generally large and only full irrigation techniques are used. However, under the new policy scenario considered in the simulations, DI could become a profitable strategy for farmers. We included DI techniques in the model for the four main irrigated crops: watermelon (*Citrullus lanatus* [Thunb.]), maize (*Zea mays* L.), melon (*Cucumis melo* L.*)* and tomato (*Solanum lycopersicum* L.). Together, these account for about 71% of the total irrigated area. We have identified DI techniques using the agronomic model CropWat developed by the FAO. This model predicts, on the basis of climatic and agronomic data, the likely yield impacts of reducing irrigation water (Clarke *et al*., 1998). The impacts are based on a simplified water balance model that calculates the water requirements of each crop in each period. These are calculated as:

$$CWR = ETo \cdot Kc \cdot Area \qquad [14]$$

where CWR indicates the global crop water requirement, Eto is the evapotranspiration level coefficient for the study area, Kc is a crop specific coefficient estimated by the model developers on the basis of experimental data and Area is the cropped area. Therefore, CWR depends also on climatic conditions, agronomic practices and soil characteristics (Doorenbos and Pruitt, 1977; Doorenbos and Kassam, 1979). The data set for CWR in the study area was developed and analyzed by Lezoche and Severini (2007).

The impact of water deficit on yields is calculated by CropWat on the basis of the following relationship:

$$\left(1-\frac{Y_a}{Y_m}\right) = K_Y \left(1-\frac{ET_a}{ET_m}\right) \qquad [15]$$

where Y_a and Y_m are actual and maximum yields, ET_a and ET_m are actual and maximum evapotranspiration and K_Y is a factor denoting the linkages between yield and evapotranspiration. This factor is crop specific and has been identified for each crop by the model developers. This relationship is estimated in the whole crop growing season considering the main crop growing periods (Doorenbos and Kassam, 1977).

The most important factor that relates evapotranspirated to applied water is irrigation efficiency, which depends on irrigation uniformity and the depth of irrigation water applied. As a consequence, the relationship between applied and evapotranspirated water is not generally linear (Reca *et al*., 2001).

Two DI techniques for each of the four crops have been identified under the assumption that those two techniques reduce irrigation levels by 5% (DI_5) or 10% (DI_{10}) with respect to the actual levels. These reductions are applied linearly to each irrigation without altering the irrigation calendar. This simplified approach is used here given the small considered reductions (5% and 10%). However, a less simplified approach should be used in future research to explore such important aspects better.

The considered water reductions do not severely affect yield levels. Furthermore, under the considered intervals, water volumes affect yield according to constant or decreasing marginal productivity (Table 2). In the simulations that follow, these results have been used to identify the expected yields of DI techniques.

The variable crop specific cost reductions shown in Table 2 are affected only by the changes in the direct cost of irrigation. However, the reductions in applied water could cause reductions not only in the costs of

Table 2. Change in crop yields and specific variable costs for deficit irrigation technologies (DI_5 and DI_{10}) with respect to full irrigation technologies (% changes)

	Yields (%)	Specific variable costs[1] (€ ha^{-1})		
		L1	L2	L3
Watermelon:				
DI_5	–2.07	–0.49	–0.64	–0.64
DI_{10}	–4.14	–0.98	–1.28	–1.28
Maize:				
DI_5	–2.00	–0.92	–1.16	–1.16
DI_{10}	–4.12	–1.84	–2.32	–2.32
Melon:				
DI_5	–2.00	–0.35	–0.46	–0.46
DI_{10}	–4.12	–0.70	–0.92	–0.92
Tomato:				
DI_5	–1.89	–0.35	–0.46	–0.46
DI_{10}	–3.79	–0.70	–0.92	–0.92

[1] They refer to all specific variable costs for each crop. The irrigation board delivers water using three non-fully connected irrigation systems, which we distinguish as sub-areas L1, L2 and L3. DI_5 and DI_{10} refer to reductions of irrigation water of 5% and 10% with respect to current full irrigation techniques.

irrigation but also in other costs such as fertilizers and harvesting (English and Raja, 1996).

Regarding the simulations, the environmental payment is applied per cubic meter of saved water: this is calculated by subtracting the actual water use from the water use observed in the baseline.

Results

The model was calibrated to 2004 data on observed cropland allocation. We created a new base case to consider important changes of the Common Agricultural Policy of the UE (CAP) introduced by the so called Midterm Review (MTR) of the 2003. In particular the new base case considers the decoupling of direct payments for cereal and other field crops (*i.e.* COP crops), the introduction of a partially coupled aid aimed at improving the quality of durum wheat and the modulation of direct aids as prescribed by Council Regulation (EC) No 1782/2003 (EC, 2003). The conditions introduced by the MTR reform will be in effect at least until 2013. Therefore, this is the new policy environment in which EU farmers will operate in the coming years. The MTR simulation is taken as the baseline from which the set of simulation regarding the introduction of environmental payments granted on the basis of the amount of water farmers save.

The simulations consider the introduction of an environment payment at different levels. These are set at € 0.10, 0.30 and 0.50 per saved cubic meter of water[2]. This last variable is calculated starting from the amount of water used in the MTR situation.

The environmental payment determines a small saving in water consumption if compared with the size of the payment. In fact, a payment of € 0.10 m^{-3} determines a saving of around 10% and a payment of € 0.50 m^{-3} determines a reduction of around 33%. In general, increasing the environmental payment level does not cause a strong reduction in water use and this behavior clearly becomes stronger as the relative water saving increases (Figure 1).

Indeed, after a certain level, further increases of the payment do not reduce water consumption. In the study area this phenomenon could occur only at very unlikely high payment levels.

As the environmental payment level increases, the amount of irrigated land decreases from 30% of UAA in the MTR baseline, to 27.5% with a payment of € 0.10 m^{-3} and to 21% with a payment of € 0.50 m^{-3}. Water use also declines while increasing the level of the environmental payment. However, the relative reduction of water use is generally higher in absolute terms than the reduction of irrigated area. In fact the reduction of water use is caused by a change in cropping patterns and by the switching from full irrigation to DI technologies.

Regarding the cropping patterns, there is a reduction in irrigated crops and, in particular, of those crops with lower gross margin value (*i.e.* corn) (Table 3). The area devoted to vegetables with higher gross margin value also decreases but to a lesser extent (*i.e.* tomato, melon and watermelon). Irrigated crops are replaced by non-irrigated crops, especially cereals such as durum wheat and oats.

The introduction of environmental payments induces farmers to switch to DI (Table 4). It is worth noting that in the 2004, DIs are not observed in the baseline, but they enter into production (even if in small quantities) while applying the MTR reform (Table 4).

[2] These figures are rather high when compared with the unitary water cost currently charged by the IB. However, as already explained, the application of the WFD is expected to increase the cost farmers will pay.

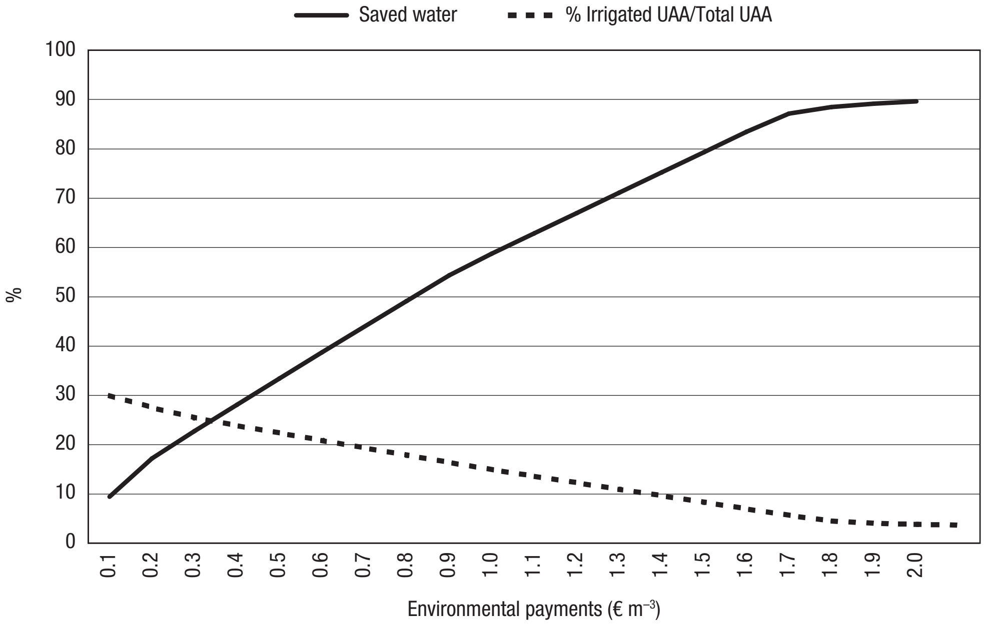

Figure 1. Reduction on water use and % irrigated UAA (utilized agricultural area) with increasing environmental payment level

Without payments, DI is used only on 2.6% of the irrigated land, with a payment of € 0.10 m^{-3}, around 8% of the considered crop area is cultivated using DI techniques. This percentage becomes about 37% when the payment is set at € 0.50 m^{-3}. Switching to DI techniques allows farmers to reduce the irrigated land proportionally less than the used water (Table 3).

The changes in cropping patterns and irrigation technologies generated by the introduction of the environmental payments have an impact on the economic results of farms.

Table 3. Impact of the environmental payments scenarios on cropping patterns for the whole study area

	MTR[1]	Environmental payments (€ m^{-3})		
		0.10	**0.30**	**0.50**
Cereal and other field crops (COP) *of which:*	2,790	0.3	1.7	3.4
Oats	382	8.0	16.6	22.2
Durum wheat	2,310	1.7	3.5	4.7
Maize	98	–64.4	–100.0	–100.0
Vegetable crops *of which:*	2,176	–5.9	–17.3	–27.9
Watermelon	326	–10.8	–32.5	–54.1
Melon	203	–10.3	–30.8	–51.3
Tomato	1,010	–10.8	–32.5	–54.1
Fodder crops *of which:*	2,204	–0.2	–1.5	–3.2
Irrigated	1,682	–0.7	–2.3	–2.7
Non irrigated	522	1.7	3.5	4.6
Other crops	827	14.8	43.7	70.6
Irrigated land (ha)	2,397	–8.1	–20.3	–30.4
Water use (1000 m^3)	5,949	–11.0	–26.0	–37.4

[1] Simulation scenario referring to the mid-term review (MTR) reform of the Common Agricultural Policy without environmental payments.

Table 4. Impact of the environmental payments on the amount of land where deficit irrigation techniques (DI_5 and DI_{10}) are used. Whole study area (ha)

	MTR[1]	Environmental payments (€ m^{-3})		
		0.10	**0.30**	**0.50**
Watermelon: Full irrigation	326	291	220	150
DI_5	–	–	–	–
DI_{10}	10	26	58	91
Maize: Full irrigation	98	35	–	–
DI_5	–	–	–	–
DI_{10}	–	–	–	–
Melon: Full irrigation	203	182	140	99
DI_5	–	–	–	–
DI_{10}	6	16	35	54
Tomato: Full irrigation	1,010	901	682	464
DI_5	–	–	–	–
DI_{10}	28	76	171	267
Total Full irrigation	1,637	1,408	1,043	712
Total DI techniques	44	118	265	412
Total irrigated	1,680	1,526	1,308	1,124
Relative weight of deficit irrigation techniques (%)				
Full irrigation	97.4	92.3	79.8	63.4
DI techniques	2.6	7.7	20.2	36.6

[1] Simulation scenario referring to the Mid-term Review (MTR) reform of the Common Agricultural Policy without environmental payments. DI_5 and DI_{10} refer to reductions of irrigation water of 5% and 10% with respect to current full irrigation techniques.

The switch to non-irrigated crops causes an extensification of cropping patterns that determines a reduction in farm revenues but also in specific variable costs. However, the farm gross margin increases if the environmental payments are taken into account. Viceversa, without environmental payments, the gross margin decreases due to the consistent reduction of the sales revenues.

Finally, it is important to note that the amount of payment per unit of irrigated land, even assuming a payment of € 0.50 m^{-3}, still has a magnitude that is below the average environmental payments currently paid under the regional Rural Development Plan for irrigated crops (Table 5). However, given the expected limited participation to the proposed payment scheme, the overall financial cost of the measure does not seem unsustainable from a financial point of view especially if the payment is set at € 0.30 m^{-3} or lower levels (Table 5).

Discussion

This paper has analyzed the possible impact of introducing environmental payments granted to farmers on the basis of the amount of water they save. This has been carried out by using an extension of the PMP Röhm and Dabbert approach that has allowed us to include DI crop techniques not observed in the reference period in the models. This inclusion is perceived as important in order to represent farmers' behavior because they can adjust not only their cropping patterns, but also the amount of water they use per unit of land. Indeed, while DI has been included in other kinds of mathematical programming models to account for this latter aspect (Reca *et al.*, 2001), this analysis has done it in a PMP modeling framework.

This approach has been proposed in order to overcome an important limitation of PMP by allowing a greater flexibility in model responses to changes in policy and economic conditions. A critical element of this approach is how to define the non-observed activities. Our study uses agronomic growth models for this purpose. However, the interaction between agronomic and economic models is not always straightforward, given that the former often assume full information and technical efficiency (Dillon and Hardtacker, 1993). Therefore, this process requires the careful in-

Table 5. Impact of the environmental payments on farm economic results for the whole study area

	MTR[1] (1,000 €)	Environmental payments (€ m^{-3})		
		0.10	0.30	0.50
		% change with respect to MTR results		
Sales revenues	17,894	–4.4	–12.5	–20.0
Specific variable costs	7,707	–4.9	–13.4	–20.9
CAP direct aids (coupled and decoupled aids)	5,370	–2.0	–1.7	3.1
Gross margin with CAP direct aids	8,704	–0.3	–2.0	–4.9
Gross margin with CAP direct aids and environmental payments	8,704	0.4	2.9	6.9
Environmental payments (1,000 €)	–	64	429	1,031
Unitary environmental payments (€ ha^{-1} of irrigated land)	–	29	225	618
Environmental payments/CAP direct aids (%)	–	1.2	8.1	18.6

[1] Simulation scenario referring to the mid-term review (MTR) reform of the Common Agricultural Policy without environmental payments.

tegration of data collected in the field with data derived from agronomic growth models.

The empirical analysis has permitted the testing of the proposed approach in the area of irrigation. However, this approach can be applied to a broader set of changes in production practices.

Furthermore, the empirical analysis has shown that, in the considered conditions, the introduction of environmental payments generates a reduction in water use and in the amount of land devoted to irrigated crops, especially those with lower relative profitability such as corn. These results seem in line with those of empirical studies conducted on the same topic on other study areas by means of farm-based mathematical programming models (Varela-Ortega, 2003). However, simulation results suggest a relatively low impact of the proposed scheme in terms of water saving at least for environmental payments of not too high levels. Indeed, environmental payments have been found to require a much higher public funding requirement than other policies in order to generate a relevant reduction of water use (Varela-Ortega, 2003).

The results suggest that, coherently with similar analysis (Bartolini *et al*., 2005), farmers' demand for water is relatively rigid in the short-run. In the considered case, this is due to several factors among which the followings. First, the difference in profitability between irrigated and rain-fed crops is large. Second, given the relatively small unitary water cost paid, the cost for irrigation water currently accounts for a very limited share of the variable specific crop costs (Table 1). Third, when the highest range of environmental payments is applied, a large share of the irrigated land is used to grow tree-crops (*e.g.* peaches) that the model keeps fixed at the base line level (Figure 1).

When environmental payment level increases, the models substitute current full irrigation with DI techniques. This behavior minimizes the reduction of the area used by irrigated crops that is caused by the decline of water use following the increase in the environmental payment level. This result supports the need to include DI techniques in the models to better depict technological adjustments of farms and to provide more accurate estimations of the impact of important water policy changes that are expected to occur in the near future.

Note that the techniques DI_5 do not enter into production. This is probably due to two reasons. First, the considered changes in per hectare water use are small and therefore these techniques are very similar to a linear combination of full irrigation and DI_{10}. Second, our model seems to penalize the relative competitiveness of the intermediate (in this case the DI_5) by introducing a large additional parameter to the linear average cost function for this group of techniques. Under the conditions represented in these scenarios, this could prevent DI_5 from entering into production. However, this limitation could be overcome by taking into consideration larger changes in per hectare water use and a larger number of alternative techniques. This could allow intermediate techniques to enter into production more easily.

The analysis has shown that the considered payments induce an improvement in farm economic results (*i.e.* gross margin with environmental payments). This occurs because the payments more than compensate for the negative impact generated by the reduction of water use. The introduction of such environmental payments may be constrained by the amount of public resources that the EU and national governments are willing and able to allocate to agro-environmental schemes. However, it is important to remember that the *Health Check* reform of the CAP has generated two important changes. On one hand it has increased the modulation rate that is going to reach 10% in 2012 (EC, 2009a). This will bring about an increase in the financial resources available for rural development policies including the agro-environmental ones. On the other hand, the *Health Check* has identified a limited set of *new challenges* for the EU agriculture to which such additional resources should be devoted. One of the new challenges refers to water management in agriculture (EC, 2009b). These changes seem to suggest that the kind of environmental payments considered in this paper may become one of the likely instruments to pursue both water saving and income support objectives.

Note that the environmental payments are much lower than the CAP direct payments: even with a payment of € 0.50 m^{-3}, environmental payments are around 19% of the CAP direct payment. This reasoning suggests that the shift of resources from CAP pillar I to pillar II measures could accommodate for the development of additional and innovative environmental payments such as the one considered in this analysis.

Finally, the water saving could have a negative effect on the financial sustainability of the Irrigation Boards given that this reduces the overall amount of payments they collects from the farmers. Given that the service provided by the IBs is often characterized by some economies of scale, this could lead the IBs to increase the level of the unitary payment in order to ensure the balancing of their budget. This could have negative consequences on farm economic results and could induce farmers to use other water sources (*e.g.* private wells) if available.

While the analysis of water-saving measures should be better addressed on a comparison of possible measures (Berbel *et al.*, 2011), the proposed analysis seems to confirm that agro-environment payments could be a part of a more strategic approach to protecting water resources (EC, 2005).

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