EAAE Congress 2002
Saragoza, 28/08-1/09 2002

Proposal for paper presentation
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Title
Water regulation and irrigated agriculture under the EU Water Framework Directive[1]

Keywords: irrigation, water, decision support system, water policy

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Summary

Water management for irrigation requires suitable policy tools able to meet social objectives and private behaviour. The legal framework in the EU is today faced with the new water framework directive (60/2000), that sets up new criteria for water management, regulation and pricing.

Among other things, the water framework directive introduces the principle of full cost recovery and the polluter pays principle for water users. For many areas of Italy, this may be a significant shift compared to present payment criteria, based on traditional rights, political prices, partial running cost coverage or others.

The aim of this paper is to analyse the problem of water regulation in agriculture as applied to irrigation issues. This is made by setting up and testing a simulation model based on the integration of a mathematical decision making model at farm level and a principal agent model at the level of irrigation boards.

The model allows to quantify water demand and the optimal regulation from the point of view of the policy maker. The results show major impacts of water availability and prices on farm income. The adoption of a mix of pricing instruments related at the same time to crop rotation, water consumption and pollution can significantly improve water policy efficacy.

[1] The paper is a common work of the authors. In particular, G.M. Bazzani has written section 3.1 and 3.2; S. Di Pasquale has written section 2; D.Viaggi has written section 3.3. and 3.4 and V.Gallerani has written section 4. Introduction and conclusions have to be attributed to all the authors.

1. Introduction

Water is becoming a major issue as a determinant of quality of life in many countries of the world. Agriculture is one of the main water-using sectors, with a share of total water use ranging from 40 to 80% of total water usage for the main EU countries.

Water management requires the knowledge of the impact of water use on ecosystems and, as a direct or indirect effect, on human well being, as well as suitable policy tools able to meet social objectives and private behaviour. The legal framework in the EU is today faced with the new water framework directive (WFD) (directive 60/2000), that sets up new criteria for water management, regulation and pricing.

The accompanying economic documents identify a general structure of the water pricing problem, defining the price as the sum of an element related to fixed cost, a charge per unit of water used and a charge per unit of pollution. Also the principle of full cost recovery and the polluter pays principle should be taken into account by regulators when setting water pricing. For many areas of Italy, this may be a significant change if compared to present payment criteria, based on traditional rights, political prices, partial running cost coverage or others.

The aim of the paper is to analyse the problem of water regulation in agriculture as applied to irrigation issues. This is made by setting up and testing a simulation model based on the integration of a mathematical decision making model at farm level and a principal agent model at the level of irrigation boards. The final aim is to create a support for the economic evaluation of the efficiency of alternative policy instruments for the application of WFD to irrigation.

The paper has the following structure. In section 2 an overview of the situation of irrigated agriculture in Italy is provided. In section 3 the methodology adopted is described, followed, in section 4, by the results. A discussion is provided in the final section

2. The water problem and irrigated agriculture in Italy

In Italy, as in many countries, the issue of water scarcity is rapidly gaining attention. Agriculture plays a major role in such issue, as it is the sectors with the higher share in water consumption, due mainly to irrigation (table n.1.).

Table n.1. - Water consumption by sector in Italy

	Year 1991		**Year 1999**	
	Billion of m3	**Percentage**	**Billion of m3**	**Percentage**
Households	8	16	7,9	19,6
Industry	12	24	8,0	19,7
Energy			4,5	11,1
Agriculture	30	60	20,1	49,6
Total	**50**	**100**	**40,6**	**100**

Source: Istat (1991) and Irsa-Cnr (1999)

The 55% of agricultural production is obtained by irrigated systems (Leoni, 1997). The irrigated surface in 2000 was around 25% of the total agricultural area, with a significant growth in the last decade (in 1993 it was around 18%). The irrigated area is a very different share of total agricultural area in different regions, ranging from 8,2% of Marche, to 66,2% of Lombardia (ISTAT, 2000). For some crops (e.g. orchards, vegetables, flowers) the irrigated area is virtually 100% of the total cultivated area. 60% of Italian agricultural export is made up of irrigated crops (Anbi, 1992; Lamoglie, 2001).

The water distribution system in Italy is mainly managed by "reclamation and irrigation boards" (RIB), that, formally speaking, are associations of farmers that control the management and distribution of water resources over a certain area. Water use regulation is based on a complex system of rights, often developed since ancient times. Water pricing works usually through surface based tariffs that hardly cover RIB costs. There are few examples of pricing per unit of water consumption.

The introduction of WFD could bring major changes for irrigated farming. Though the application should be strongly differentiated at regional level, according to river basin organisations, some major criteria are common for all countries.

The first is the principle of full cost recovery. According to this principle, the user of water should bear all the costs of water provision. From an agricultural perspective this would mean a net increase of water prices, as today, in Italy, only a part of running costs for water provision are borne by the final users.

A second major principle introduced is the polluter pays principle (PPP). According to the PPP, water users should bear the cost of pollution as well as the costs of the water resources and of water provision. This could make things worse for irrigated farms as long as irrigation is often associated to more intensive farming systems, including a higher use of pollutants.

The pricing of water would be a recommended instrument for reducing water use and water pollution. Putting things together, the suggested pricing structure after the WFD is implemented may be made up of at least three components: a fixed amount for unit of irrigated land, a price per unit of water used and a price per unit of pollution. The final price should take into account both the full cost recovery and incentive considerations in order to bring to the best social use of water.

From a farm point of view, the main risk from WFD is the increase in water price[2], that could lead to major impacts on farming income and employment. The evaluation of the impacts of higher water prices and the search for better policies are hence two major issues for agricultural policy making.

3. Methodology

3.1. The overall methodology

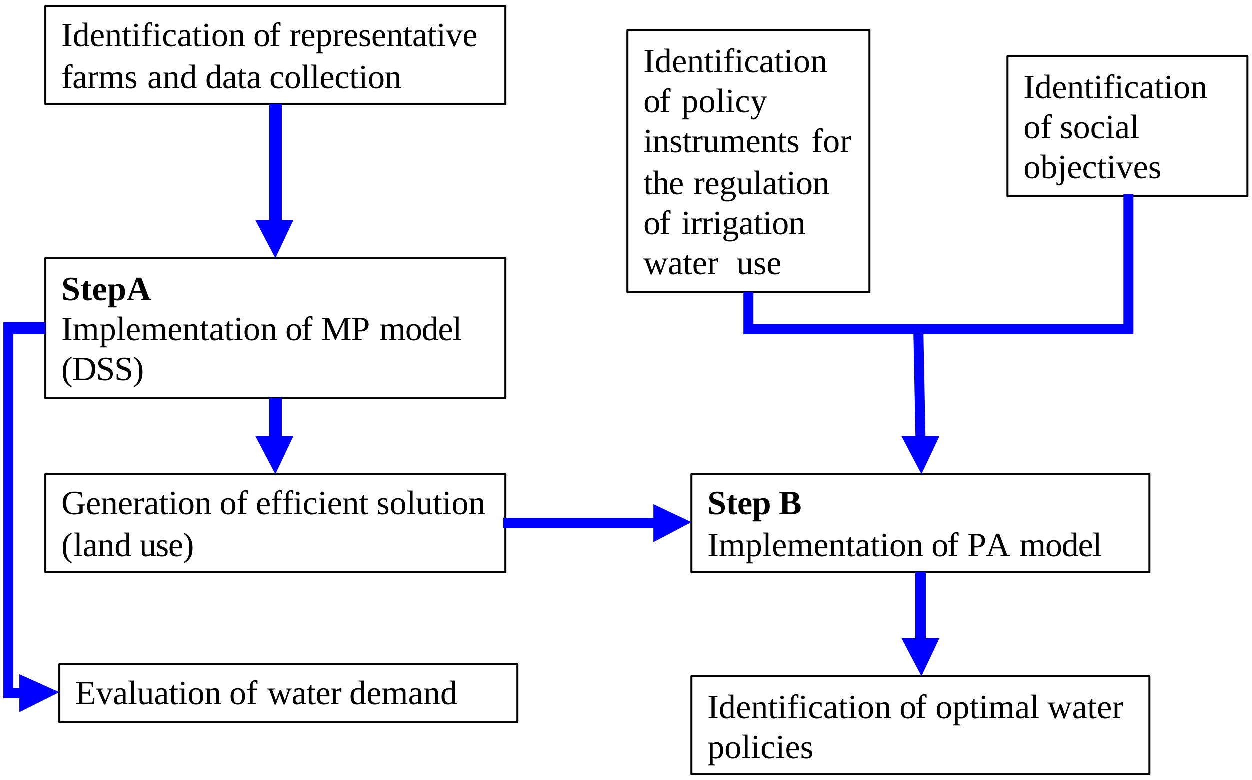
A very wide literature exists about the pricing of water resources related to agriculture, both in terms of policy analysis and in terms of instruments for decision support[3].

The main point of the proposed methodology is the attempt to couple mathematical programming (MP) models and principal agent (PA) models (Figure n.1.).

[2] Actually other instruments, such as usage thresholds during key periods, may be used, but are not considered in this paper.

[3] Only to remind some of the main works related to water, see for example Dinar and Subramanian (1997); Dosi and Easter (2000), Garrido et al. (1999).

Figure n.1. Methodology



The first part of the model (step A) is based on the use of mathematical programming. This instrument, frequently used in the literature for irrigation problems, allows the search for optimal crop rotation or activity combinations, for representative farms[4]. The problem is cast as a constrained maximisation, where constraints include water availability and the objective function is farm profit or net income. The same model also allows the generation of a demand function for water.

This part of the model has been implemented in the form of a Decision Support System (DSS) able to easily allow data entry and provide simulations. The model takes into account the activities required by the production cycle; this allows to analytically quantify the utilisation of water, chemicals, labour and machinery and their costs, considering different irrigation systems at territorial and farm level. The program, which operates as a Windows application, is highly friendly. It can be used at farm level as a decision support tool for technicians and farmers, while at public level it allows to study and define water tariffs and policy, as well as to evaluate the impacts of a territorial transformation due to increase or shortage of water supply.

While the DSS can be used as an independent tool, in the context of the present work its main role is that of generating the set of alternative feasible crop rotations that can be adopted by the farm under analysis. The set of feasible crop rotations is produced together with income, water consumption and any other useful parameters and can be evaluated through the PA model (step B). The PA model is aimed at identifying the optimal incentive scheme from the point of view of the public regulator, given the opportunity cost of water, the social cost of environmental externalities and the social cost of public transfers (Kreps, 1990; Rasmusen, 1994). It is able to identify the optimal crop rotation from a social point of view and the best way to give to the farmer suitable incentives to choose that crop rotation.

[4] See Bazzani et al. (2001), Berbel (2000), Dono (2001), Howitt (1980), Moore et al (1992, 1994a, 1994b), Schaible (1997), Varela-Ortega et al. (1998).

3.2. The DSS and the identification of feasible crop rotations

In the context of this work, the DSS is mainly used in order to estimate valuable combinations of farm activities, useful to be fed into the PA model. Each combination represents a crop rotation and other possible activities, such as the choice of a particular irrigation system.

In principle, any possible crop rotation could be used as input for the model. Nevertheless, given a linear mathematical problem, the optimisation algorithm of the linear programming would choose the solution among corner points. In order to use the same rationale here, the DSS includes an algorithm able to find the set of possible corner points of the model. The algorithm is based on a parametrization of gross margins of the model. The corner points identified are fed into the PA model.

It is necessary to point out that the corner points identified in such a way may or may not be efficient from the private point of view, depending on the actual price combination. Also, each corner point represents a combination of crops and is associated to some economic, social and environmental results. So, from a social point of view, it is possible to express a hierarchy of preferred corner points. The problem is that the hierarchy depends on the social cost of providing incentives to the farmer to produce at that point. Here is where the PA model comes in.

For our purposes the integration between the two models appears particularly useful, as the DSS allows to identify only "relevant" solutions, instead of the infinite possible ones. Also, this avoids problem of infeasibility in the following PA model.

Finally, it allows to verify the results of the PA by feeding them into the MP model.

3.3. The Principal-Agent model with risk neutral farmer

PA models can be used in order to identify optimal regulation parameters given agent's and principal's utility functions (Kreps, 1990; Rasmusen, 1994). In our case, we assume the existence of a public or semi-public decision maker (a RIB) interested in maximising the social welfare through the regulation of the irrigation activity of one or more agents (farmers). The problem is to find the optimal regulation taking into account the constraints given by the WFD and the economic relationships between single actors. Let us suppose that there is only one principal and one agent.

We assume that, for our purposes, the behaviour of the farmer may be represented by discrete actions $a_i = \{s_{ij}\}$, each one made up of a vector of values s of the decision variables j, with $i=(1,\dots, I)$ and $j=(1,\dots.J)$. Assuming linear relationships, we can interpret s_{ij} as the degree of activation of each farm activity and a_i as a vector of such degrees of activation in a farm representation that uses a fixed coefficients technology. We assume further that the results (technical, economic and environmental) of each crop depend on some state of nature θ_p, with p=1,…, P, each with probability π_p. According to standard technology representation under uncertainty, as a consequence, farm income, water use and environmental results may be represented as a function of the state of nature occurring.

We can assume that the objective function of the public decision maker, concerning the regulation, includes the following components:

- Farm income;
- Value of the water used;
- Value of externalities (positive or negative) produced;
- Costs for water abstraction and delivery, included administrative and transaction costs;
- Distortionary effects due to social transfers (taxes or subsidies);
- Monitoring and control costs.

Assuming that the problem of the principal is to maximise social welfare, it is possible to find out the solution using a two steps procedure (Kreps, 1990; Rasmusen, 1994).

The first consists in finding the least cost solution that guarantees the carrying out of each possible action by the agent. In the second, the aim is to choose the action a_i that maximises social welfare. While the latter of these steps is quite simple, se first one is rather more complex.

First note that for each farm action, farm income (from market), the value of water used and of externalities produced do not change depending on the devised incentive scheme. So, in order to proceed to cost minimisation we have to take into account only the cost of money transfer to public authority, the cost of water provision and the cost of control and monitoring. Assuming both the principal and the agent risk neutral, the problem of cost minimisation representing our first step may be cast as follows:

$$\min K_i = e\left[\sum_j s_{ij} \cdot \sum_p \boldsymbol{p}_p \left(\left|F_j\right| + \sum_h \left|a_h\right| \cdot Q_{jph} + \sum_k \left|b_k\right| \cdot Y_{jpk}\right) + \left|T\right|\right] + Kd \ + Kc \ \cdot f$$

subject to the following constraints:

IC1:

$$\sum_j s_{ij} \cdot \sum_p \boldsymbol{p}_p \left[ML_{jp} - \left(F_j + \sum_h \ a_h \ \cdot Q_{jph} + \sum_k \ b_k \ \cdot Y_{jpk}\right)\right] \geq$$

$$\sum_j s_{i'j} \cdot \sum_p \boldsymbol{p}_p \left[ML_{jp} - \left(F_j + \sum_h \ a_h Q_{jph} + \sum_k \ b_k \cdot Y_{jpk}\right)\right]$$

for any i’ different from i.

IC2:

$$\sum_j s_{ij} \cdot \sum_p \boldsymbol{p}_p \left[ML_{jp} - \left(F_j + \sum_h \ a_h Q_{jph} + \sum_k \ b_k \cdot Y_{jpk}\right)\right] \geq \sum_j s_{ij} \cdot \sum_p \boldsymbol{p}_p (ML_{jp} - f \ \cdot S)$$

BC:

$$\sum_j s_{ij} \cdot \sum_p \boldsymbol{p}_p \left(F_j + \sum_h \ a_h Q_{jph} + \sum_k \ b_k \cdot Y_{jpk}\right) + T \geq Kd \ + Kc \ \cdot f$$

Where:

K_i = social cost of action i;

ML_{jp} = gross margin of the activity j;

e = distortionary effect caused by taxation

Q_{jph} =quantity of water consumed by each activity j;

Y_{jpk} = quantity of pollutant produced by each activity j;

v_h = unit social value of water (opportunity cost) by period h;

z_k = unit social value (positive or negative) of each environmental parameter k;

Kd = abstraction and distribution costs of the RIB;

Kc = monitoring costs able to guarantee 100% compliance and sure information transfer (f=1);

T = public (state) transfers obtained by the RIB;

S = sanction in case of non compliance.

In this problem, the decision variables are the following:

F_j = fixed charge per unit of activation (surface) of each activity (crop); it may be positive or negative (subsidy);

a_h = charge per unit of water used in each period h;

b_k = charge per unit of environmental parameter k;

f = level of monitoring accuracy (0-1);

The result of this constrained optimization is a bundle of regulation parameters. This bundle represents the least cost solution able to persuade the farmer to accept each of the different action considered in the evaluation. The model is based on the minimisation of social cost subject to three constraints.

The social cost is the sum of the social cost of public transfers, the cost of water provision and monitoring cost. Monitoring costs are the result of the cost of total control times the level of monitoring accuracy, following a modified version of the linear monitoring cost used by Choe and Fraser (1999). While costs for monitoring and water provision are fully considered in the public decision maker objective function, transfers account only for a fraction, determined by the distortionary effect of taxation (*e*), i.e. the inefficiency due to the subtraction of money from the private sector (White and Ozanne, 1997).

A participation constraint is not needed as long as any farmer included in the area of the RIB has to submit to charges for irrigation (farmers are not free to chose to participate or not).

Equation IC1 is a standard incentive constraint of a PA model. It guarantees that the regulation framework is such that each action considered is better than any of the others, for the same farm. In the presence of the bundle of incentives produced by the model, the farmer will choose that action and not another.

Equation IC2 guarantees that it is more profitable to comply and tell the truth to the regulation body instead of doing the opposite. It contains a sanction, that, in this context, is assumed as an exogenous variable. The structure of the model implies that the regulator is interested in obtaining full compliance.

Equation BC is the balance constraint for the regulatory body. It guarantees that, according to the WFD, the regulating body achieves a full cost recovery.

IC2 and BC contribute mainly to determine the total amount of payment requested to the farmer, while IC1 directly affects the level of charges/subsidies for each activity.

It is possible to show that the combination of IC2 and BC provides a lower bound to the sum of transfers required for the regulation and an upper bound to f. The lower bound to the sum of payments required is given by:

$$\sum_j s_{ij} \cdot \sum_p \pi_p \left(F_j + \sum_h a_h \cdot Q_{jph} + \sum_k b_k \cdot Y_{jpk} \right) \geq \frac{\sum_j s_{ij} S(Kd - T)}{\sum_j s_{ij} S - Kc}$$

The upper bound on f is given by:

$$f \leq \frac{Kd - T}{\sum_j s_{ij} S - Kc}$$

When both IC2 and BC hold with equality, we have the minimum payment and the maximum monitoring accuracy. In such case, there is a fixed ratio between payments and monitoring accuracy given by:

$$\frac{\sum_j s_{ij} \cdot \sum_p \pi_p \left(F_j + \sum_h a_h \cdot Q_{jph} + \sum_k b_k \cdot Y_{jpk} \right)}{f} = \sum_j s_{ij} S$$

The model can of course be simplified or made more complete in many ways. One way is to consider more than one farm, with possibly different characteristics. In this case, a constraint could be added, managing the differentiation of incentives in order to overcome adverse selection.

Also, decision variables may be structured in a different way, allowing for different variability of incentive schemes. For example charges per hectare can be the same for all crops and not differentiated between crops as in the model.

The second step is simply carried out by choosing the action that maximises social benefit B:

$$B_i = \sum_p \pi_p \sum_j s_{ij} \cdot \left[ML_{jp} - \left(\sum_h v_h \cdot Q_{jhp} + \sum_k z_k \cdot Y_{jkp} \right) \right] - K_i$$

In this case the social benefit is composed by the farmer's gross margin, minus the value of the externalities produced, minus the social cost of the regulation determined in the previous step. In case of positive externalities the formulation still holds and the value of the externalities sum to the gross margin.

3.4. The Principal-Agent model with risk averse farmer

Risk aversion by the agent has been considered in order to provide a first evaluation of its relevance and direction in affecting the results.

When we introduce risk aversion by the agent, we have to revise the constraints IC1 and IC2. According to the literature, we assume the "textbook" representation in which the expected utility is given by the sum over the possible states of nature of the square root of the income in each state of nature. In order to take into account that incentives may be both positive and negative, so may add or subtract to income, we use a slightly modified representation in which the square root is taken separately for the positive part and for the negative part of the incentive scheme (see also Choe and Fraser, 1999 about this issue).

In effects, the regulation parameters may be both positive or negative, i.e. may be charges (when positive) or subsidies (when negative). We denote F_j^+ as the positive charge per hectare of each activity (crop); a_h^+ as the positive charge per unit of water used in each period *h* and b_k^+ the positive charge per unit of environmental parameter *k*. Instead we denote the decision variables as F_j^-, a_h^-, b_k^- when they are negative charges (i.e. subsidies).

Also, we denote with E_{jp}^+, the sum of positive charges per unit of activity and state of nature, as:

$$E_{jp}^+ = \left(F_j^+ + \sum_h a_h^+ \cdot Q_{jhp} + \sum_k b_k^+ \cdot Y_{jkp} \right)$$

and respectively E_{jp}^- as the sum of negative charges. So we can rewrite our constraints as:

IC1:

$$\sum_p \pi_p \left\{ \left[\sum_j s_{ij} \cdot \left(ML_{jp} - E^-_{jp} \right) \right]^{1/2} - \left(\sum_j s_{ij} \cdot E^+_{jp} \right)^{1/2} \right\} \geq$$

$$\sum_p \pi_p \left\{ \left[\sum_j s_{i'j} \cdot \left(ML_{jp} - E^-_{jp} \right) \right]^{1/2} - \left(\sum_j s_{iù'j} \cdot E^+_{jp} \right)^{1/2} \right\}$$

for any i' different from i.

IC2:

$$\sum_p \pi_p \left\{ \left[\sum_j s_{ij} \cdot \left(ML_{jp} - E^-_{jp} \right) \right]^{1/2} - \left(\sum_j s_{ij} \cdot E^+_{jp} \right)^{1/2} \right\} \geq$$

$$\sum_p \pi_p \left\{ \sum_j s_{ij} \cdot (ML_j - f \cdot S) \right\}^{1/2}$$

This representation also avoids problems with non positive income, that may occur for some actions.

We must note that this solution is not completely satisfying from at least two points of view. First, it is not sure that the square root represents the actual degree of preference of the farmer. Also, by dividing the function into two parts, though the main mathematical requirements are satisfied, we further affect the relative magnitude of utility differentials between different solutions. It is not the aim of this paper to further discuss this issue, adding to the growing literature about risk representation for farming decision making (see, for example, Saxowsky and Wachenheim, 2001; Pennings and Garcia, 2001). At this stage of the research, this solution is considered sufficient to get some first insights into the problem of the connection to risk aversion.

4. Results

The model has been tested on a hypothetical farm that may be considered representative of a very common agricultural system of the province of Bologna (Emilia-Romagna, in the south of the Po Valley), based on cereal cultivation, coupled with industrial cultivation of vegetables such as potato and onion. Potato, in particular, finds here a very good production environment, and is protected through a local trademark. It relies very much on water availability in order to improve production and to reduce yield variability[5].

The farm has 15 hectares of arable crops and is specialised in a potato-cereal rotation. It is analysed using only one environmental indicator and a constant social cost for water across irrigation periods during the year.

Through parametrisation of the DSS, 81 alternative crop rotations have been identified as corner points, i.e. locally efficient solutions, of the MP tool. Such alternative rotations have been introduced in the PA model for different levels of social cost of water consumption and of nitrogen emission. In this way, the optimal (maximising social benefit) crop rotation for each combination of value of resources/externalities have been obtained.

Figures n.2a and n.2.b represent the mapping of the optimal crop rotation given different combinations of the value of water and the value of environmental externalities. Table n.2 represents the composition of the selected crop rotations and their results at farm and social level (for both risk neutral and risk averse farmers).

[5] We also assume *e*=0,2 (drawn from the literature, see White and Ozanne, 1997), *Kd*=1600 euro/year and *Kc*=2500 euro/year (both estimated on the basis of local data).

Figure n.2.a. Dominant solutions for different levels of social cost of water (euro/m3) and environmental damage by nitrogen (euro/kg) - risk neutral

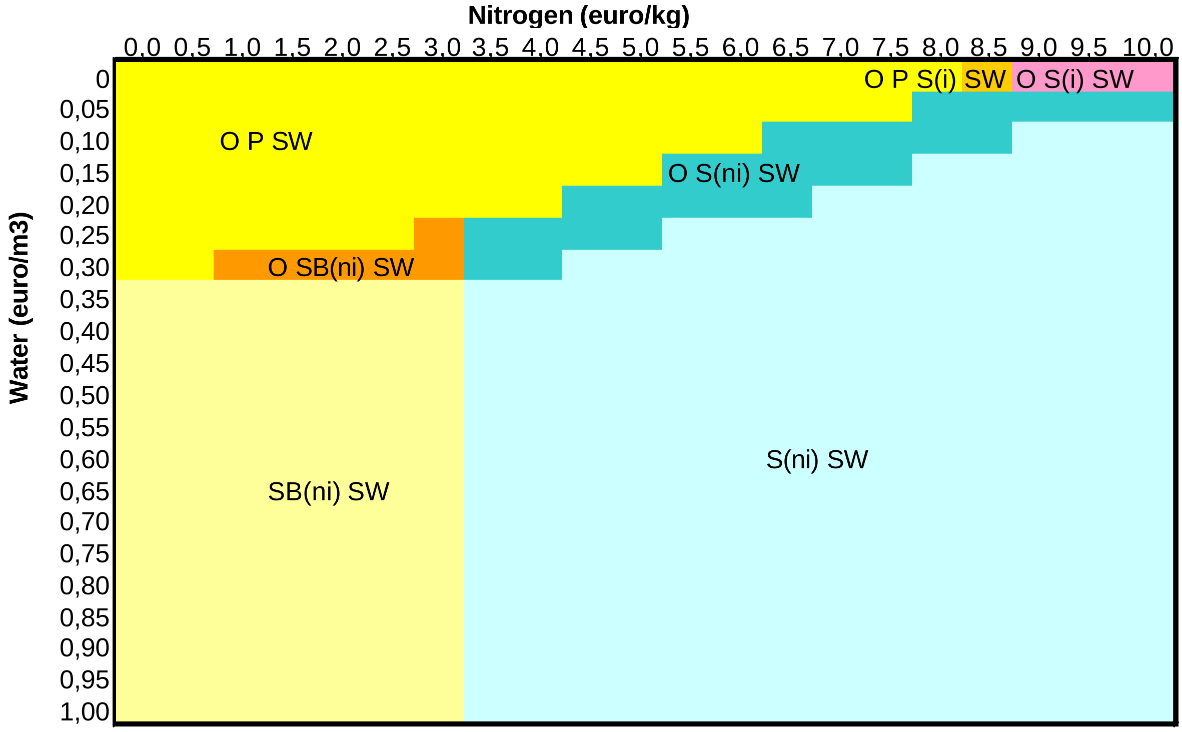


Figure n.2.b. The dominant solutions for different levels of social cost of water (euro/m3) and environmental damage by nitrogen (euro/kg) - risk averse

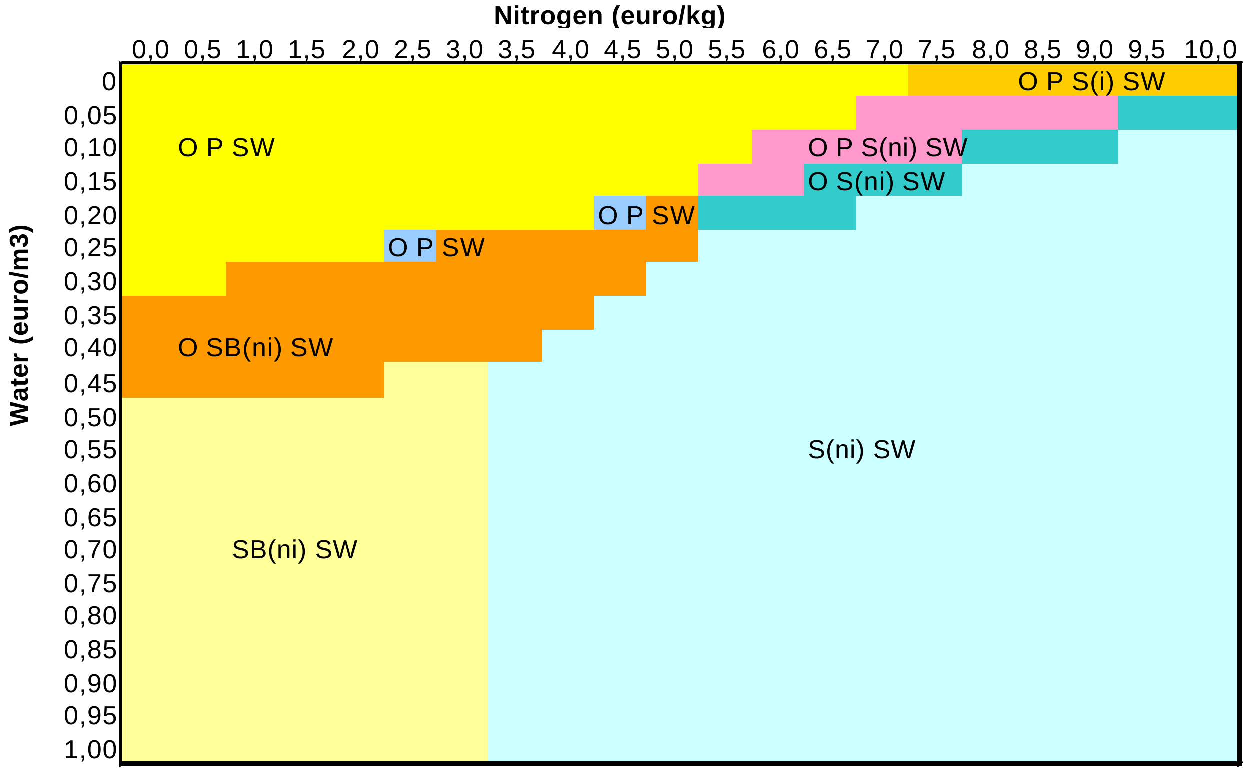


Table n.2. - Dominant crop rotations (ha)

	O P SW	O P S(i) SW	O P SW	O P S(ni) SW	O SB(ni) SW	O S(i) SW	O S(ni) SW	SB(ni) SW	S(ni) SW
Onion (i)	3	3	3	3	3	3	3		
Potato (i)	6	5	4,5	5					
Sugar beet (ni)					4,5			7,5	
Sugar beet (i)									
Maize (ni)									
Maize (i)									
Soya (ni)				2			4,5		7,5
Soya (i)		2				4,5			
Durum wheat (ni)									
Soft wheat (ni)	6	5	7,5	5	7,5	7,5	7,5	7,5	7,5
Barley (ni)									
Irrigation plant	4,5	5	3,75	4	1,5	3,75	1,5	0	0
Gross margin (without incentives) (euro)	**18466**	**18366**	**18398**	**18385**	**14581**	**13854**	**13789**	**13050**	**11730**
Transfer costs (RN)	443	615	626	624	443	443	443	443	443
Monitoring costs (RN)	615	615	615	615	615	615	615	615	615
Water provision cost (RN)	1600	1600	1600	1600	1600	1600	1600	1600	1600
Total policy cost (RN)	**2658**	**2830**	**2841**	**2840**	**2658**	**2658**	**2658**	**2658**	**2658**
Total payment by farmers (RN)	**2215**	**3073**	**3131**	**3122**	**2215**	**2215**	**2215**	**2215**	**2215**
Gross margin (after incentives)	**16250**	**15292**	**15267**	**15263**	**12365**	**11639**	**11573**	**10835**	**9515**
Transfer costs (RA)	432	440	428	436	429	442	442	441	441
Monitoring costs (RA)	559	602	539	578	547	608	607	607	605
Water provision cost (RA)	1600	1600	1600	1600	1600	1600	1600	1600	1600
Total policy cost (RA)	**2591**	**2642**	**2567**	**2613**	**2576**	**2649**	**2649**	**2649**	**2646**
Total payment by farmers (RA)	**2796**	**3010**	**2694**	**2888**	**2734**	**3038**	**3037**	**3037**	**3023**
Gross margin after incentives) (RA) (euro)	**16306**	**15306**	**15344**	**15301**	**12434**	**11647**	**11581**	**10843**	**9525**

Note: i=irrigated; ni=non irrigated

It is necessary to point out that the figures do not represent water demand, but socially optimal crop rates depending on the value of water, the value of externalities and the best regulation mechanism identified.

As it may be expected, increasing the social cost of water, the optimal solution shifts towards non-irrigated rotations. Two things are worth to be pointed out. First, the move from irrigated to non irrigated rotations happens for values of water above 0,3 euro, about 6-10 ten times higher than the present price. This is due to the high value of agricultural production obtained through irrigation. Secondly, above this level the crop rotation change dramatically, without relevant substitution between irrigated crops. This is due partly to the actual economic relationship between different crops. Potato and Onion are the two main crops using water. When the social value of water is so high that it is not worth to use it for such crops, it tends to be unlikely that it is worth to use it for any other combination. This effect is made more important, in actual decision making, by rigidities and technical constraints, that make the adaptation a discontinuous matter instead of a smooth process towards less water consuming crops.

On the other side it is necessary to note that, in this case, the shift towards non irrigated crops is helped by CAP subsidies of which wheat and soja benefit, while potato, onion and sugar beet do not. In their absence, the shift would be surely slower. Another consequence is that the shift towards dry farming would mean, in this case, an increase in CAP payment[6].

When assuming a risk averse farmer, the move is slower. This is due to the fact that non irrigated sugar beet, maize or soya are needed in the dry solutions (for rotation reasons) but are also the crops with the higher variability of yields. This means that higher incentives are needed in order to persuade the farmer to shift towards such crop rotations. Basically, risk aversion appears to slow

[6] They have not be considered in the utility function of the RIB for two reasons. The first is that they come from the EU and it is likely that the local decision maker is less interested in the social cost of their use. Secondly, they may be considered as a "due" support to farm income and not as a part of an incentive payment for controlling agriculture production and its environmental consequences.

down the hypothetical change towards less water consuming farming, as they are, at least partially, associated with higher variability.

The payments account for about 14-16% of the gross margin. Their total amount is mainly determined by the costs for water provision and monitoring. The shift towards non irrigated rotations causes a reduction in farm income (-37% in the extreme case). It is also associated to a dramatic change in labour organisation, due to the move towards much less intensive crops.

The total social cost of intervention is almost the same in every case. Small variations, within a range of less then 10%, may be found both for different farm rotations and between risk and non risk farmer. According to the result obtained up to now, hence, risk aversion does not appear to change very much the total cost of the incentive scheme.

The results are obtained supposing the use of the optimal regulation system for each rotation, that is illustrated, for a risk neutral farmer, in table n.3.a.

Table n.3.a. - Optimal regulation scheme for each crop rotation – risk neutral faremer

	O P SW	O P S(i) SW	O SB(ni) SW	O S(i) SW	O S(ni) SW	SB(ni) SW	S(ni) SW
Monitoring accuracy	0,25	0,25	0,25	0,25	0,25	0,25	0,25
Tax per crop (euro £/ha)							
Durum wheat (ni)						117,0	117,0
Sugar beet (ni)				161,4	176,0	39,4	215,4
Sugar beet (i)		89,1		126,4	113,9	11,9	58,3
Soft wheat (ni)	139,0	139,0	139,0	139,0		256,0	256,0
Barley (ni)						7,4	
Maize (ni)				129,4	144,0	106,5	183,4
Maize (i)		165,1	91,6	221,9	201,6		127,5
Soya (ni)							39,4
Soya (i)							
Potato (i)	79,3	189,9	553,9	600,0	600,0	600,0	600,0
Onion (i)	301,9		241,0	204,0	190,8	370,5	466,8
Tax per irrigation plant (euro/unit)							
Tax on water (euro/m3)							
period 1			0,15	0,18	0,20	0,18	0,26
period 2							
period 3					0,03		0,12
Environmental Tax (euro/kg N) n							

The model allows for a mix of instruments that are only partially used in the selected rotations, but are widely used throughout other crop rotations that are not represented here.

Basically, the optimal solutions are a mix of taxation per crop and charges per unit of water use. In strictly economic terms, taxes per crops are the less expensive instrument for the public administration. In addition, they can be used when water consumption is not measurable (which is very frequent in Italy). On the other side, charges per unit of water consumption are more effective in inducing a change in technology towards water saving technologies.

When taxes are applied, they show to be very high compared to the present tariffs (even 20 times higher). Taxes on nitrogen are basically non necessary due to substantial correlation between water and nitrogen use.

The level of accuracy of monitoring tends to be equal between different rotations and to stick to the upper bound.

The regulation scheme appears rather different when the farmer is assumed to be risk averse (table n.3.b).

Table n.3.b. - Optimal regulation scheme for each crop rotation – risk averse

	O P SW	O P S(i) SW	O P SW	O P S(ni) SW	O SB(ni) SW	O S(ni) SW	SB(ni) SW	S(ni) SW
Monitoring accuracy	0,22	0,24	0,22	0,23	0,22	0,24	0,24	0,24
Tax per crop (euro £/ha)								
Durum wheat (ni)	5,4	44,35		49,8				
Sugar beet (ni)	60,7	52,95	131,2	59,7	188,9			
Sugar beet (i)								
Soft wheat (ni)	35,4	91,58		94,4				
Barley (ni)		25,85		26,07				
Maize (ni)	53,2	41,66	123,09	47,9	178,4			
Maize (i)		11,89						
Soya (ni)	26,9		88,4		133,5	7,3	95,9	
Soya (i)			8,4			16,6	94,0	11,5
Potato (i)		84,65		23,0			76,4	
Onion (i)							155,4	
Tax per irrigation plant (euro/unit)								
Tax on water (euro/m3)								
period 1		0,15					0,04	
period 2	0,27		0,38	0,26	0,94		0,03	
period 3								
Environmental Tax (euro/kg N)								
n						4,53	3,16	7,35

Some crops are not charged anymore while others are charged more than before. Generally speaking, charges per hectare appear lower than before and less distributed across different crops. Payments per unit of water used and payment per unit of nitrogen are generally higher. In particular, the most extreme (less privately profitable) crop rotations are obtained by very strong payments on nitrogen consumption. Altogether, with a risk averse farmer, the optimal policy sees a shift of uncertainty from the farmer (risk averse) to the RIB (risk neutral), leading to a completely different outcome in terms of regulation scheme.

5. Discussion

The model described in this paper allows the simulation of water management as the interaction between a regulating body and a farmer, allowing to quantify the optimal regulation from the point of view of the policy maker. It is not intended to substitute the public decision making process, but to support it through quantitative data and simulations, helping in adapting to continuous changes in the policy context.

The results of the case study show that major changes are needed in crop choice in order to meet increasing social value given to water resources and pollution. On the other side, if such values translate into actual policies, they are likely to have major impacts on farm income and organisation. This confirms the relevance of the issue for farming management and policy, and the need of a suitable decision making system based on effective instruments as those presented in this paper.

The adoption of a mix of pricing instruments can significantly improve water policy efficiency, though the degree of such improvement depends on the technical relation between water consumption and each other parameter considered (e.g. environmental indicators).

Risk aversion by farmers tends to produce a slower adaptation to water prices, no much changes in the total amount of incentives needed, but relevant implications in term of optimal instrument combination.

Though any change in the actual institutional system is forces to happen somehow gradually, the WFD appears as an occasion for a major revision of water regulation throughout Europe. Some of such revisions, as in the present papers, appears in contrast with the social ad economic objectives of farmers as well as with economic, social and environmental objectives of CAP. Nevertheless the reform of water regulation should be better interpreted in a proactive way as the occasion to anticipate potentially growing conflicts and to make water use altogether more sustainable.

In order to support such search for satisfying solution, simulation models can add some insights, though they cannot of course provide a complete representation of the actual complexity of institutional relationships among actors. A number of improvements can be carried out on the model, with particular attention to a more reliable way of getting to a better estimation of the actual impact of risk. Further, the analysis should be widened in order to take into account a larger number of crops and a higher number of technologies, included different irrigation systems.

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