Chapter 2
Irrigation Water Resource in a Rice-Growing Area: Economic Evaluation under Different Pricing Conditions

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Abstract Water scarcity is an increasing phenomenon affecting all sectors of economic interest. This problem is stressing agriculture as well, and in particular primary activities that use huge amounts of the resource to maintain their productions at sufficiently high levels. A way to contrast scarcity is the improvement of the efficiency of water allocation and the reduction of its losses, through the adoption of political instruments and pricing aimed to a more aware use of the resource itself. In this context, the Water Framework Directive, in order to assign an appropriate cost to irrigation water, urges member states to introduce the concept of full cost, and to apply a volumetric supply fee promoting the rationalization of the resource, thus playing a role in addressing emerging and future problems of water scarcity. However, several studies have already demonstrated through modeling approaches that these interventions could strongly affect farms' choices and performances, resulting in consequences that would have repercussions on the whole agricultural system. The study aims to evaluate economic performances of farms in a typical rice-cultivated area in Lombardy, Northern Italy, under different supply tariff levels. A simple programming model has been used to run a scenario analysis. Structural features of farms, their productive inputs and performances are reported in current conditions, under different pricing and progressively increasing fee levels, in order to evaluate their effects on farms' economic performances and operative strategies. The obtained results allow for a first identification of critical points in the water management of the area and hypothesize interventions for a better resource allocation, as a useful instrument for supporting future policies on water resources.

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C. Zopounidis et al. (eds.), *Agricultural Cooperative Management and Policy*, Cooperative Management, DOI: 10.1007/978-3-319-06635-6_2,

2.1 Introduction

Water represents a fundamental element for all sectors of economic, social, and environmental interest. Particularly in agriculture, it undoubtedly plays a key role as a fundamental productive input for the conduction of all the related activities, in arid and semi-arid regions, as well as temperate ones. In the former, water allows to obtain a sufficient crop production, while in the latter it maintains yields at high levels, reducing the risk of loss of the product (Tarimo et al. 1998; Iglesias et al. 2005; IPPC 2012). However, in relation to several emerging issues, its importance is increasing, even in such areas where water availability for the primary sector has not traditionally been limiting. Also for irrigated agriculture, in fact, a quantitative reduction of the resource is occurring, due to the global phenomena of climate change (Fischler et al. 2007), an increasing population and rapid urbanization, which are emphasizing the conflict of water use among different sectors, as a result of an increasing demand on the part of each one, at the same time exacerbating the effects of decreased usability (UNEP 1999). Water scarcity in agriculture is becoming a significant issue and it inevitably has repercussions both on the productive and economic performances of farms, modifying in the long-term period their competitiveness, and burdening the possibility of continuing the activity. Along with water scarcity, and as a possible strategy to face it, the need for reducing the wastes of the resource also has to be considered. Water as an economic asset with limited availability (ICWE 1992) is to be protected through promoting its efficient and equal, which is possible only by the attribution of a fair price. The estimation of water irrigation costs is then a significant topic with an important role in supporting water regulations, allowing decision makers to make aware choices to face water shortages.

2.2 The Cost of the Resource

The Water Framework Directive (WFD) 60/2000/EC (European Parliament and the Council of EU 2000) emphasizes the allocation of a fair price for irrigation water and calls on member states for the introduction of the so-called "*full cost*" (Fig. 2.1), which, taking into account financial, opportunity and environmental costs, could represent the practical application of the "polluter-pays principle": it ensures that the end user pays a price high enough to recover all the costs arising from the use of water, and its adoption reduces wastes and nonvirtuous behaviors caused by an underestimation of the resource.

In agriculture, applied fees are much lower than those hypothesized by regulatory bodies which could lead to an increase in irrigation costs; paradoxically, the farmer, as the end user of the resource, would then be in the condition of having less water at a higher cost; therefore this situation would not be sustainable from the farmers' point of view. In order to achieve a sustainable use of the resource, the

Fig. 2.1 Structure of the full cost (WATECO 2003, modified)

<table>
<tr><td>Environmental costs not related to water</td><td rowspan="2">Environmental costs (external)</td><td rowspan="6">Economic costs</td></tr>
<tr><td>Environmental costs related to water</td></tr>
<tr><td>Opportunity costs (scarcity)</td><td>Cost of the resource (external)</td></tr>
<tr><td>Other direct costs</td><td rowspan="3">Financial costs (including environmental and opportunity costs already internalized)</td></tr>
<tr><td>Administrative costs</td></tr>
<tr><td>Capital, operating and maintenance costs</td></tr>
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suppliers can adopt different modalities for the delivery of water service. Pricing and fees differ according to their efficiency in promoting a more rational use of irrigation water. A fixed fee set per irrigated or irrigable hectare tends not to encourage such practices, but is relatively easier to adopt and may in some cases represent the most recommended solution (Giannoccaro et al. 2007); volumetric fees, instead, determine a more aware use of water, but could have unit costs much lower than the actual cost of the resource. WFD suggests preferentially using a volumetric rate, as it would represent an economic instrument able both to reduce water consumption and cover all the costs of water service. It represents a more transparent and efficient (Tsur et al. 2003) pricing method, since it is based on the water quantity actually supplied. As several studies have already demonstrated (Dono et al. 2006; Giannoccaro et al. 2007; Bartolini et al. 2007), a different tariff level, a different pricing and the increase of irrigation water costs influence farmers' choices, and lead to a significant reduction in water consumption, at the expense of withdrawals from wells and private water sources, as well as the need for management and/or productive changes; but these strategies, such as a reduced irrigated area, crop diversification toward less water-demanding crops, an increase in the efficiency of distribution and a different method of water application, can finally result in a significant decrease in farm income.

Moreover, some authors consider the use of incentives to be not so encouraging of good behavior and the assignment of a political price to water service supply to be an inefficient management system, not stimulating proper use (Rogers et al. 2002), but efficient pricing, which may determine undesirable effects on farmers' decisions or environmental implications not immediately anticipated. In the fields of ancient irrigation, such as rice-cultivated areas in Northern Italy, environmental aspects also related to multiple use of the resource must be considered (Cadario and Bischetti 2006): even though water distribution techniques are technically inefficient and characterized by huge losses due to filtration, the complex system, and water network developed over the centuries has allowed the creation of valuable paranatural aquatic environments. Even in these areas with high natural and environmental value the quantification of environmental costs is something difficult (EEB 2001), leading to an uncertain estimation of full cost.

Finally, it must be considered that irrigation water value is strictly linked to that of the agricultural production it contributes to. Consequently, a higher water cost inevitably reflects on water use efficiency and productivity (Molden 1997; Seckler et al. 1998; Kassam and Smith 2001), an increase of which could represent a further way to achieve an efficient use of water.

2.3 Modeling for Irrigation Water Management

A valid support to policy makers and to decisional processes lies in the results of appropriate tools, such as mathematical programming models. They provide information not directly observable and allow simulations of different scenarios related to changes in agricultural policies, resource management or market development, and can guide decision makers toward the identification of the most suitable interventions to achieve economic and environmental targets of water policies.

Economic analyses of irrigation water are based on the formalization and implementation of both econometric and programming models, at different scales and levels (farm, local, regional). Among them the regional level is able to answer the requirements of the WFD, which states that the catchment area is the unit for the analysis and the integrated management of water resources.

The econometric approach, based on less informative inputs, has demonstrated on several occasions the possibility to estimate a function of operating costs of water distribution, in irrigation districts and consortia (Dono 2003; Dono and Giraldo 2010; Giraldo 2011; Dono et al. 2011); more often the economic analysis of irrigated agriculture is realized through the application of linear programming models (mono-objective, multicriteria, stochastic discrete) to evaluate the impacts derived from alternative conditions, both internal and external to the system: each simulation generates a new solution showing the effects of the changes themselves on crops, technological choices, use of productive inputs, and economic performances of farms (Dono 2003; Bazzani et al. 2005; Dono et al., 2008; Giannoccaro et al. 2008; Bazzani and Zucaro 2008; Bazzani and Scardigno 2008; Dono and Giraldo 2010; Giraldo 2010; Dono et al. 2011). However, these models require the collection and processing of a large amount of economic and productive data and information; even though they are useful to understand the features of the agricultural system by identifying relationships between the use of inputs and productive levels, their results strongly depend on the constraints imposed on the model.

In the same context, the use of Positive Mathematical Programming (PMP) (Howitt 1995; Paris and Howitt 1998) is recently spreading. This new approach requires a limited amount of data to perfectly calibrate the model for the reference period, according to three main phases: specification of a linear programming model that uses all the information available, reconstruction of a total variable cost (Arfini and Paris 1995), and formulation of a nonlinear programming model to be used to perform simulations. Its application for water resource analyses is, however, currently underdeveloped. In this regard, it recalls the work of Blanco et al. (2004) which considers the impact of pricing policies on two irrigation districts in Spain by specifying a cost function for each one, what Cortignani and Severini (2008, 2009) have developed in relation to territorial analysis, also following the introduction of tariffs differentiated depending on the season.

These models can be used to face issues related to the variation in the cost of the water and its availability, but the possibility of analyzing future scenarios is limited, since they do not allow the consideration of new and different production activities compared to the reference situation.

2.4 Aims and Analysis: Methodology

The paper aims to simulate possible changes in water management and water use, if different types and levels of payment were introduced. In many parts of Northern Italy irrigation consortia apply to the supply of water a fee based on the served surface, rather than according to the distributed volume. In order to simulate the farmers' behavior in the adaptation to face a different basis for water payment, a mathematical programming model has been implemented. The analysis has been carried out in a rice-cultivated area in Lombardy, Northern Italy, characterized by peculiar uses of the resource itself and particularly suited for this analysis.

Data collection has been carried out through direct surveys at sample farms, using results of *ad hoc* experimentations conducted in an experimental farm in the same area.

The selection of rice-growing farms operating in the district started from their extraction from the regional database *Sistema Informativo Agricolo della Regione Lombardia* (SIARL), their classification on the basis of Utilized Agricultural Areas (UAA) of rice, and the sampling within each class. To each farm a specific questionnaire requiring information about the crop year 2010–2011 was submitted and filled through direct surveys to farmers, for a total of 19 surveys carried out and a total rice-cultivated area of 730 ha. The cultivated area is dedicated to four main cultivars, namely *Gladio, Loto, Baldo*, and *Selenio*.

Data were then elaborated to describe the features of the system, and used for the identification and implementation of a model, returning current economic and productive conditions of farms. In order to evaluate the effects of new managerial and/or productive strategies on cultivated areas (possible reduction of the irrigated area, crop diversification, increase in the distribution efficiency and different method of water provision), it has also been used to make scenario analysis, related to a different pricing system and levels.

2.4.1 Case Study Area: Main Features

The case study area is located in a typical rice-growing district in South-Eastern Lombardy, i.e., the so-called Lomellina, with a particular focus on the area of San Giorgio di Lomellina (PV). Agriculture in the district is mainly dedicated to rice, with a marginal portion for other arable crops, such as corn, soybean and poplar. The consortium supplier (*Associazione Irrigazione Est Sesia*) provides water to farms, deriving it from Cavour Canal, Arbogna River and leakages, even though supplies from private sources also exist. The distribution of water is mostly continuous and, for a lesser part, it refers to pre-established rotating shifts. Combinations between water dispensation and cultivation strategies return in different typologies for the conduction of rice-fields, as shown in Table 2.1.

According to conducted experimentations, crop production is linked to water and agronomic management, since differences among yields exist.

The estimation of distributed water indicates the traditional method as the most water-requiring, while the differentiation of sowing techniques shows a lower overall water distribution for soil-seeding (Table 2.2). At the same delivery typology, the determining factor increasing its resource management typology during the growing season. Water quantity seems, then, to affect yields, suggesting that lower provision and availability cause a lower production.

2.4.2 The Implemented Model

For an economic evaluation of irrigation water in the district, a simple nonlinear programming model was developed. A decisional variable set in simulations is the rice-growing area ($xcrop_{f,c}$) in each farm (f index) subject to irrigation according to the different methods of water supply and agronomic management (c index).

The objective function Z aims to maximize gross margin of the group of farms, as a difference between obtainable revenues (R) and costs supported during the whole growing season (C), including, along with production costs, water supply costs and water management costs (Castellani et al. 2008) (see also Table 2.3). It takes the following synthetic form:

$$Z = \sum_{f,c} (R_{f,c} - C_{f,c})$$

Revenues encompass those from CAP subsidies for rice-growing activity and those from the sale of paddy rice. In detail, the former amount to an average premium of 850€/ha, with a reduction of 8 % for the part exceeding 5,000€, according to European guidelines: each farm can obtain an average more than 30,400€, which currently represents 20 % of total revenues; the remaining 80 % is due to the sale of paddy rice at market prices in 2011, equal to 331€/ton (Camera di Commercio di Pavia 2011).

Table 2.1 Different conductions of rice-fields: general characteristics

Irrigation type code	Water dispensation	Water management		Agronomic management	Farms (n.)	% UAA	Yield (tons/ha)
CFW	Continuous	Continuous flooding. Water flows continuously for the whole duration of the crop cycle. Submersions are interrupted by 3 or 4 dries in correspondence with certain phases of the cycle or treatments with herbicides or fertilizers		Water-seeding after the submersion of the field	10	50.63	9.72
CFS	Continuous	Continuous flooding. Water flows continuously for the whole duration of the crop cycle. Submersions are interrupted by 3 or 4 dries in correspondence with certain phases of the cycle or treatments with herbicides or fertilizers		Soil-seeding; the ground remains dry until the rice has reached the stage of the 4^{th}-5^{th} leaf, then the normal regime of submersion is restored	5	8.95	8.33
SCFW	Rotating shifts	Intermittent flooding. Water is available continuously only during predefined shifts	Continuous flooding during the shift	Water-seeding after the submersion of the field	1	8.02	9.72
SCFS	Rotating shifts	Intermittent flooding. Water is available continuously only during predefined shifts	Continuous flooding during the shift	Soil-seeding before the first irrigation	2	10.02	8.33
SIS	Rotating shifts	Intermittent flooding. Water is available continuously only during predefined shifts	Flowing irrigation, trying to maintain water on the ground until the next shift	Soil-seeding before the first irrigation	6	21.91	7.81

Table 2.2 Seasonal water dispensation and flow for each crop type

Irrigation type	Distributed water (m^3/ha)	Water flow (i_c) ($l * s^{-1}\ ha^{-1}$)
CFW	22,712 ± 1,696	2.4
CFS	20,842 ± 114	2.4
SCFW	17,075[a]	1.5
SCFS	13,073 ± 84	1.5
SIS	5,476 ± 6,344	1.5

[a] one data available only

Table 2.3 Elements of the implemented model

Total revenues (R)	CAP subsidies	Contribution for single payment with reduction for the modulation
	Sale of paddy-rice	Revenues from selling rice to processing industries
Direct costs (C)	*Water supply cost*	
	Water supply cost	Payment to Irrigation Consortium for water supply during watering season
	Water management costs	
	Maintenance and repair of technical means used for irrigation	Managing costs for irrigation structures inside the farm (maintenance, repair and operations)
	Costs for energy and consumables	Fuel, oil, electricity for pumping, lifting and distributing water
	Labor costs	Manpower for water management
	Amortization of machines	Share of deterioration of the machines used for irrigation
	Other production costs	
	Farm-level operations, from sowing to harvest	

As summarized in Table 2.3, various expenses are traced back to three main cost categories. The expenses related to water supply costs refer to the current tariff condition set by the consortium and equal 278.62€/ha, or the volumetric rates introduced in different scenarios. 15 % of total costs are due to this aspect.

Water management costs, as suggested by Lazzari and Mazzetto (2005), take into account various economic aspects linked to irrigation practices. Some technical elements needed for the estimation of this cost category have been directly surveyed at farms (working capacity of the pump and power of the tractor used for irrigation, number of irrigations during watering season), while others have been assumed as starting points (hourly labor cost, value of a new machine, its economic and physical life, repair and maintenance factors and coefficient, and depreciation rate). The estimation of these costs reveals that they represent 20 % of direct costs, and in particular 12 % are linked to labor, 7 % to the management of technical means, and 4 % to consumables.

Finally production costs, or costs for operations at the farm level from sowing to harvest, are estimated to be 1,200€/ha, returning almost one third (65 %) of the total expenses that farms support.

Z is subjected to two main farm-level and district-level constraints regarding land and water. Land balance ensures that no more land than the total available in each farm (land_f) is cultivated (2.1) and that cultivated areas ($a_{f,c}$) still maintain the same water dispensation, continuous (2.2a) or not (2.2b):

$$\sum_c \text{xcrop}_{f,c} \leq \text{land}_f \tag{2.1}$$

$$\text{xcrop}_{f,\text{CFW}} + \text{xcrop}_{f,\text{CFS}} \leq a_{f,\text{CFW}} + a_{f,\text{CFS}} \tag{2.2a}$$

$$\text{xcrop}_{f,\text{SCFW}} + \text{xcrop}_{f,\text{SCFS}} + \text{xcrop}_{f,\text{SIS}} \leq a_{f,\text{SCFW}} + a_{f,\text{SCFS}} + a_{f,\text{SIS}} \tag{2.2b}$$

Water balance ensures that water flow resulting from the model is not higher than that currently provided by the consortium (i_c), differing for each water dispensation (see Table 2.2):

$$\sum_c i_c * \text{xcrop}_{f,c} \leq \sum_c i_c * a_{f,c}$$

2.4.3 Scenario Analysis

A scenario analysis has then been performed. The first condition (scenario #0) applies the maximization to the current situation, characterized by a water payment per irrigated hectare. In further scenarios, a volumetric fee replaces the current one, *ceteris paribus*. In scenario #1 the fee is calculated so as to return the same expenditure, deriving from the fixed rate per hectare.

Prices introduced in scenarios #2 and #3 allow us to understand which types of water management are chosen in order to maximize the gross margin, and at the same time, how much water is saved. This information is synthesized in economic and productive parameters. In particular the following have been considered:

- *Total costs and revenues*;
- *Water cost*, or the price of irrigation water (PU, in €/m^3), as the ratio between costs of irrigation and water available to the farm, and distributed:

$$PU\ [€/m^3] = \text{costs of irrigation/distributed water}$$

- *Water productivity,* defined as the ratio between total yield (in tons) and its water consumption (m^3) during the season due to evapotranspiration (Teixeira et al. 2008; Vazifedoust et al. 2008); we have instead calculated it as yield compared to total amount of water used during the watering season, not considering line losses, namely the amount potentially distributed each year according to the available resource; this productivity can be named *Irrigation Water Productivity*:

$$\text{IWP}\,[\text{g/kg}] = \text{total yield/distributed water} * 1000$$

In addition, the *Economic Water Productivity (EWP)* has also been considered based on the market value of the crop (Igbadun et al. 2006; Palanisami and Suresh Kumar 2006; Teixeira et al. 2008; Vazifedoust et al. 2008):

$$EWP[€/\text{m}^3] = \text{crop economic value/distributed water}$$

2.5 Results and Comments

The model was solved through the software GAMS (*General Algebric Modeling System*) (Brooke et al. 1988; Rosenthal 2007) and has allowed the generation and display of several data output.

The model returned information about current structural features of farms, their productive inputs, as well as the productive and economic performances of each one and for every type of culture, allowing comparisons between farm and cultural types, homogeneous or not.

Optimal management of cultivated areas in comparison with current conditions is given in Table 2.4. The maximization of overall margin leads in any case to managerial and agronomic choices quite far from what really applied. In the current situation, the fee for water supply in the area analyzed is equal to 278€/ha, compared to the circulated volumes during watering season, which correspond to 0.017€/m^3.

Fixed fees per hectare do not seem to encourage water saving, since areas with continuous supply are suggested to be cultivated according to water seeding, which is more water-demanding than soil-seeding, and those provided periodically shift to the most demanding method within the category (SCFW). In this case, water management costs are brought down, rather than those relating to water supply. On the contrary, the adoption of different pricing has more evident effects both on typology of water management and agronomic strategies: in relation to periodic irrigations, water saving techniques are preferred. The opportunity to adopt dry or semi-dry cultivation is confirmed by previous surveys carried out in the same area: during the season 2004–2005, 5.4 % of the denounced rice-fields in the S. Giorgio di Lomellina area were soil-seeded, and from 2008 so far this percentage is passed to almost 30 %, with peak values of 37 %.[1] The volumetric

[1] These results derive from a study carried out at the experimental farm of Centro Ricerche sul Riso (*Rice Research Center*) in Castello d'Agogna (PV), pertaining to Ente Nazionale Risi (www.enterisi.it).

Table 2.4 Cultivated areas (%UAA) per irrigation type in different scenarios

Irrigation type	Currently Fee = 278€/ha	Scenario #0 Fee = 0.017€/m^3	Scenario #1 Fee = 0.03€/m^3	Scenario #2 Fee = 0.05€/m^3	Scenario #3 Fee = 0.11€/m^3
CFW	50.5	59.0	31.0	28.0	15.1
CFS	8.5		28.1	31.0	44.0
SCFW	8.2	41.0	12.3		
SCFS	10.3		28.6	41.0	40.1
SIS	22.5				0.8

fees hypothesized to be adopted have also allowed to identify cost levels favoring different irrigation techniques: with a tariff of 0.03€/m^3, part of the surface served with continuous dispensation is managed with delayed flooding (CFS). Similarly, most of the surface served by rotating shift is converted to SCFS type (seeding before the first irrigation). The more the fee increases, the more water-saving methods are preferred. With a tariff equal to 0.05€/m^3, CFS and SCFS are the most used methods, whilst in the presence of a fee equal to 0.11€/m^3, the SIS irrigation type begins to be chosen. At this level of price, in fact, the gross margin begins to be more favourable than that returned by irrigation systems ensuring higher yields.

2.5.1 Costs Analysis

The fee type currently adopted links proportional water supply cost to irrigated areas, independently from the amount of available water. Irrigation water supply costs expressed in a volumetric rate show that the lower costs are, the lower water distribution is. Actually, however, the adoption of periodic irrigation is independent of farmers' will: since the fee is set by a consortium, whenever it is modified, it would consequently affect these aspects.

Inevitably higher fee levels would mainly affect supply costs (Tables 2.5 and 2.6). For continuous dispensation, water supply costs rise proportionally to the fee introduced. Volumetric fees higher than 0.05€/m^3 lead to supply costs higher for a unit size than those deriving from a fixed fee per hectare. In these unfavourable conditions, farmers are driven to choose irrigation systems that, using less water, ensure a minor expense for the supply of the resource.

Total costs related to irrigation (Table 2.7) differ from each other according to the operative procedures adopted by each farm for the irrigation practice. However, farm water management costs remain quite constant amongst irrigation typologies, with an average value around 700€/ha, since irrigation is essentially by gravity and energy consumptions are negligible. The relevant elements in this sense seem to be the components related to the maintenance of irrigation network and labor costs, very little depending on volumes and not very compressible with a

Table 2.5 Water supply cost (€/ha), for each irrigation type in different scenarios

Irrigation type	Currently	Scenario #1	Scenario #2	Scenario #3
CFW	278	673	118	2,391
CFS		627	1,108	2,401
SCFW		244		
SCFS		133	266	578
SIS				78

Table 2.6 Water cost (€/m^3) in different scenarios

Irrigation type	Currently	Scenario #1	Scenario #2	Scenario #3
CFW	0.04	0.06	0.09	0.15
CFS	0.05	0.06	0.09	0.15
SCFW	0.10	0.11		
SCFS	0.17	0.18	0.19	0.25
SIS	0.13			1.05

Table 2.7 Costs (€/ha) related to farm water use (supply and management) in different scenarios

Irrigation type	Currently	Scenario #1	Scenario #2	Scenario #3
CFW	1,009	1,412	1,923	3,128
CFS	1,003	1,346	1,826	3,113
SCFW	963	928		
SCFS	979	816	949	1,226
SIS	953			717

quantitative reduction of distributed water. In these cases, higher outputs are due to an increased labor for periodic irrigations, as confirmed by water use cost: a higher increase is, in fact, observable in correspondence of periodic irrigations.

2.5.2 Gross Margin Analysis and Water Productivity

Since different pricing and pricing levels do not affect total revenues, as they depend only on the amount of cultivated area, economic performances in terms of gross margins mostly depend on costs. However, as observed in Table 2.8, they do not show significant differences among irrigation typologies and scenarios as well; this is due to the specific objective function utilized that imposes the maximization of the overall margin of the group of farms, and not the single margins of each individual farm. However, if considered in purely economic terms (€), different scenarios lead to a decrease in the overall margin, with a diminution in comparison to the current condition ranging from −5 to −77 %.

Table 2.8 Gross margin (€/ha) in different scenarios

Irrigation type	Currently	Scenario #1	Scenario #2	Scenario #3
CFW	4,021	4,021	4,022	4,023
CFS	3,933	3,929	3,929	3,928
SCFW	4,026	4,024		
SCFS	3,932	3,929	3,929	3,928
SIS	3,436			3,495

Table 2.9 Irrigation water productivity (g/kg) in different scenarios

Irrigation type	Currently	Scenario #1	Scenario #2	Scenario #3
CFW	0.42	0.44	0.44	0.47
CFS	0.46	0.45	0.45	0.45
SCFW	1.02	1.20		
SCFS	2.13	2.14	1.89	1.89
SIS	1.36			11.76

Water productivity expresses at what extent different irrigation typologies contribute to the productive and economic performances of farms. It does not directly depend on the imposed tariff level, as essentially based on seasonal water distribution, but rather from the amount of distributed water; however, it is affected by the effects an increased tariff can produce on the management of cultivated areas: dissimilar values then result according to different scenarios, to which diverse amounts of distributed water correspond.

Irrigation Water Productivity (Table 2.9) may be intended as a proxy for water use efficiency, not from an agronomic point of view but rather in terms of technical-management efficiency. A lower provision to the field still allows for quite uniform yields, despite being lower than those from traditional conduction. Thus it would derive a higher value in correspondence to a minor use of resource, i.e., alternative irrigation techniques. These deviations are not immediately identifiable by analyzing each single irrigation typology, but IWP values are higher if the dispensation is not continuous, particularly evident in the case of SIS, while a more traditional conduction (CFW and CFS) does not show significant variations despite increasing fees. On the other hand, if rising tariffs lead to more water-saving methods, a slight change in the overall productivity along scenarios occurs (respectively +1 % from #1 to #2, +4 % from #1 to #3 and +12 % from currently to #3).

Economic Water Productivity, meant as the ratio between the value of obtained production and distributed water, represents the remunerativeness of the resource and shows the same trend of IWP (Table 2.10), as they are directly linked. A higher value indicates a better capability in deriving a certain revenue from crop production, even in combination with a more efficient management of water.

The progressive rise of the tariff leads to not particularly significant improvements, passing from 0.58€/m^3 in scenario #1 to 0.66€/m^3 in scenario #3. This means that while the tariff increases ten times (from 0.017 to 0.11€/m^3), economic

Table 2.10 Economic water productivity (€/m^3) in different scenarios

Irrigation type	Currently	Scenario #1	Scenario #2	Scenario #3
CFW	0.14	0.14	0.15	0.16
CFS	0.15	0.15	0.15	0.15
SCFW	0.40	0.40		
SCFS	0.71	0.71	0.63	0.63
SIS	0.45			3.90

productivity rises in the order of 12 %, suggesting, at least for this aspect, that higher supply costs do not cause particularly negative effects on economic performances.

However, it must be considered that productivity values represent the lowest possible ones (minimum benchmark), as the starting assumption for the definition of productivity itself has stated that water volumes are gross volumes, not considering overall losses of the resource (along line losses and water flows).

2.6 Conclusions

In rice–paddy fields, the adoption of nontraditional managerial and agronomic techniques allows the achievement of positive targets in terms of water saving and use efficiency, expressed by water productivity. From an economic point of view, they do not substantially modify revenues of farms but affect their costs; in particular for dry cultivation, it could be necessary to increase workforce or labor per worker, which could lead to higher costs for manpower. The increase in water supply cost could also determine a better allocation of the resource.

The adoption of a volumetric rate appears as a solution with contrasting effects. It is a valid incentive for diversification of irrigation techniques toward more water-saving methods, but it is also inevitably accompanied with negative economic effects, such as lower margins, due to the need to apply tariff levels to the limitation of water quantities distributed. This leads also to the reconsideration of the concept of water use efficiency, which nowadays appears relatively high, given the ability of the system to handle huge volumes with modest costs. The model shows that such costs are also slightly compressible, as, with the reduction of distributed volumes, costs of water management vary little.

It should however be noted that the introduction of volumetric rates must be accompanied by accurate assessments about two important aspects. The first concerns the need to overcome the rigidity of supply still practiced by consortia. The possibility for suppliers in reducing the amount of water to farms, or increasing its cost (and then a decrease in demand), as well as a factor changing their managerial aspects and their farming systems, could determine a less efficient allocation of the resource, affecting hydrological cycles on a local scale, interfering and changing the water returns to farms, surface water bodies and groundwater. In this sense, a different irrigation method may result in a delay in the loading of the water table and a lowering in the water table itself can occur (in particular for dry cultivation). Similarly, a higher technical and infrastructural efficiency able to reduce distribution losses can have implications in the recharging and supplying of water sources, eliminating the potential benefits of reallocation, even if in many cases a large part of the water flow available to farms comes from internal recirculation, as a means to contrast the reduction of the water demand. A dry cultivation could finally affect the created paranatural aquatic environments. In fact the environmental role of rice fields and their irrigation systems must be considered, not just in the study area but throughout the rice-growing area of Lombardy and Piedmont. The circulation of very high volumes of water has significant effects on habitats constituted over time, becoming important ecosystems, even recognized at the Community level (SPAs Rice fields of Lomellina). For this reason, water-saving should be carefully evaluated according to the environmental functions that traditional irrigation systems perform in large parts of the territory.

These important considerations must be properly considered in order to make a complete economic evaluation of water resources. In this sense, it is then important to identify the best method for the estimation of environmental costs, since this step plays a key role as a starting point toward the quantification of the *full cost*, which represents itself as a crucial instrument in order to strengthen decisional support to policy makers.

Acknowledgments Results presented in this chapter are part of the activities carried out for the research funded by Regione Lombardia, fondo per la promozione di Accordi Istituzionali, project BIOGESTECA 15083/RCC.

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Springer

http://www.springer.com/978-3-319-06634-9

Agricultural Cooperative Management and Policy
New Robust, Reliable and Coherent Modelling Tools
Zopounidis, C.; Kalogeras, N.; Mattas, K.; Dijk, G.;
Baourakis, G. (Eds.)
2014, XIV, 422 p. 98 illus., Hardcover
ISBN: 978-3-319-06634-9