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An integrated tool for water policy in agriculture

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Abstract: The definition of proper tools to support the implementation of Water Framework Directive (WFD) is an urgent task in the European Union (EU). Agriculture deserves special attention since in most countries water consumption is higher than in other sectors and pollution due to irrigated agricultural activity is often a serious problem, while social and cultural issues are relevant. The paper presents a program called DSIRR designed to conduct an integrated analysis of water use in agriculture considering agronomic, hydraulic, economic and environmental aspects as well as complexity and uncertainty for decision making. The tool permits to analyze in great detail the relevant production systems existing in a catchment integrating stakeholders perspectives. The impact of markets, water and agricultural policies, climate, technological innovation can be assessed and the ex-ante analysis of economic instruments, suggested by WFD for cost recovery according with polluter-pays principle, conducted. Scenario analysis is used to cope with uncertainty. The paper presents a study conducted in the Po Basin in Italy comparing the impact of a water pricing and of the EU agricultural policy reform on annual and perennial crops systems. A set of indicators quantifies important differences in social, economical and environmental dimensions and suggests to adopt selective interventions. The results permit to appreciate the relevance of the tool to generate information to support the participatory policy process of basin plan implementation. A graphical user interface, a modular architecture, an open structure, a rich set of models, standardized database, make DSIRR a flexible and powerful tool for a more sustainable agriculture and a sound water policy in agriculture.

***Keywords**:* Decision Support, Water, Agriculture, Economic analysis, Policy

1 INTRODUCTION

There is nowadays a strong agreement that water is a strategic resource which requires protection and intervention. The 2000/60/EC Directive, known as Water Framework Directive (WFD), defines the basic principles of sustainable water policy in the European Union (EU). The Directive requires an integrated participative water resources policy, which simulation models and decision support DS should support. An impressive activity is currently observed in the field of integrated catchment modelling not only in EU. In fact the analysis and modelling of human-technology-environment systems and the implications of complexity and uncertainty for management concepts and decision making represent a promising approach which requires the contribute of scientists working in different fields and disciplines.

This paper presents a program called "Decision Support for Irrigation" (DSIRR), which focuses on water use and policy in agriculture, integrating economic models with agronomic and engineering information. The contribution is organized as follows. First the policy context is briefly analyzed. The requirement for modelling irrigated agriculture for policy analysis is discussed in the second section, while the third one describes the tool in a non technical way. Results from an Italian case study focusing on water pricing in the Po Basin are illustrated in the next section. The final section presents conclusions and suggestions for further development based on the described model.

2 THE POLICY CONTEXT

2.1 Water policy in Europe

WFD aims to reach within 2015 a "good status" for all water. Economic analysis and instruments receive great attention in the Directive. At this regard it is clearly pointed out that the principle of recovery of the costs of water services, including environmental and resource costs, should be adopted in accordance with the polluter-pays principle (Preamble 38, Articles 9 & 13 and Annex VII). It is well recognised that an economic analysis of water services based on long-term forecasts of supply and demand in the river basin district is necessary for this purpose. Local specificities are considered and the subsidiarity principle is suggested to deal with them. Diversity in conditions and needs should be taken into account in the planning and execution of measures to ensure protection and sustainable use of water in the framework of the river basin. WFD asks member states to conduct a disaggregate analysis into at least the tree main economic sectors: industry, households and agriculture. But is some cases, particularly when social conflict due to water scarcity and/or environmental problems is high, the level of detail could be much higher. In those cases the comprehension of the mechanisms which determine water pattern uses and actors behaviours could be necessary to design proper interventions and policies.

2.2 The EU Common Agricultural Policy

The EU the Common Agricultural Policy (CAP) is currently experiencing a new reform, the so called Mid Term Review 2003. The reform aims to solve internal and external conflicts and proceeds along the path started in 1992 and reinforced in 1999 with Agenda 2000. CAP looks for social consensus, in a context of EU enlargement and market globalization, facing severe budgetary constraints. The current reform shifts the focus on a more sustainable agriculture with out giving up the farm income support. The reform moves in the direction of a decoupled policy with internal prices more in line with the world market, which means lower prices for most commodities, and farm income support in the form of direct payments to compensate for the previous reduction. Decoupling supports from production will reduce market distortions, while modulation and eco-conditionality of farm support will guarantee equity and environmental sustainability, respectively.

3 MODELLING IRRIGATED AGRICULTURE FOR POLICY

3.1 Water and agriculture

The tool here presented tries to support a participatory planning process for water in the agricultural sector, that in most countries shows the higher water consumption. This is particularly true in southern Europe where irrigation itself represents over 50% of total demand. In order to design policies capable to reduce consumption and increase water quality the relation water-agriculture should be addressed in all its complexity (Ward et al., 2002). A good description of the processes, considering both the technical and the behavioral aspects, should be adopted. The scale of the analysis is therefore “micro” and representative actors, the farmers, should be considered. Environmental impacts are indirect effects of their activity which should be properly addressed when social welfare is considered and WFD is a case. In an economic context water represents a production factor, which enlarges substantially the farmers’ set of choices in terms of available crops and processes. Irrigation have other important effects among which the increase of production in quantitative terms is not the main one. In many cases the higher quality of production and the reduction of risk due to uncertain and unstable climate conditions are prevalent, this is particularly true for vegetables and fruit. Furthermore water permits to standardize production over space and time, and this is becoming a stringent requirement to access global markets. In many countries irrigated agriculture contributes to Gross Domestic Product (GDP) and export in a substantial way.

The relation agriculture-environment is complex. On one side, natural environment is in developed countries an artifact and the agricultural sector is the main responsible for its creation and preservation[1]. On the other hand pollution due to the agricultural activity is often a serious problem. There is a strong evidence that the use of water in agriculture favors more intensive practices which are often associated with a higher use of chemicals. But the relation irrigated agriculture environmental pollution is not linear, site specific conditions are determinant for the final environmental state; so great caution should be used to derive general conclusions.

An aspect which deserves attention is how water is distributed at farm level, which means irrigation technology. Differences exist among techniques in terms of efficient use of water, but also in terms of farm income and labor requirements. Sound policies can increase water saving favoring technology innovation.

3.2 Water pricing, an incentive economic instrument

Water charges and prices are identified in the WFD as basic measures for achieving its environmental objectives, so a key issue is the assessment whether pricing policies provide appropriate incentives for users to reduce their water uses and pollution. It is therefore essential to verify ex-ante if pricing can:

- create the financial incentive to shift to technologies and practices that ensure a better use of available resources;
- incentive users to shift to less polluting input and practices.

Economic theory explains that in general price and quantity are linked by an inverse relation. This is true also for water, but this function is not liner and not constant, since price is only one of many variables which influence the amount of water used (Joahansson et al., 2002). The proportionality between water bill and water used and amount of pollution discharged is not enough. A key question is how do prices lead to changes in the demand for water? The answer depends on the

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[1] Appreciated landscapes depend on water availability in agriculture, many examples can be found in Italy. Furthermore irrigation networks are often used to drain rain.

price elasticity of demand[2], which can be easily calculated from water demand curves. But to derive these functions is not an easy task since historical data are generally missing; models, including economic modules, represent a viable solution.

4 DSIRR

DSIRR is an interactive, flexible, transparent and adaptable computer based decision support (DS) developed to support the recognition and the solution of complex strategic problems for improved decision making and policy design. The tool uses data and models, provides a graphical user-friendly interface, and can incorporate the decision makers' own insights. The previous characteristics are relevant to favor stakeholders' involvement in the basin plan definition process requested by the WFD.

4.1 Which support from the tool?

Two reforms, in water and in agriculture, affect the primary sector. Their conjoint analysis is therefore essential, adopting a time horizon which should also consider other major sources of uncertainties like climate change and macroeconomic conditions of governance and markets. In this respect the support coming from DSIRR could be valuable since it permits to develop some of the economic analysis requested by the WFD, it aims to:

- Conduct an economic analysis of water uses in agriculture at River Basin level but considering the relevant difference existing among the coexisting production systems;
- To assess trends in water demand according with different scenario for markets, agricultural policy and climate;
- To assess the potential role of water pricing and its implications on cost-recovery;
- To assess the impact of other water policies (e.g. environmental taxes, subsidies and restriction in water supply);
- To assess the impact of innovation in irrigation technology as well as in agriculture (e.g. new crops and varieties less water demanding or more resistant to plant diseases or water stress).

In all these cases DSIRR permits a multi-dimensional assessment quantifying:

- The sustainability of irrigated agriculture for farmers in terms of farm income;
- The social implication in terms of employment;
- The environmental pressure of the agricultural activity via selected indicators.

4.2 The DS: a non technical description

From the existing literature emerge that economic models seem well suited to describe and analyze decision process and policy. A body of economic literature focuses on agriculture and irrigation. The consideration of stakeholders' preferences and their inclusion into models is an important requirement to predict the effect of policy intervention. Recent literature shows that multicriteria (MC) paradigm favors a good description of farmers' behavior (Berbel et al., 1998; Gómez-Limón et al., 2000 and 2002). Following this approach DSIRR analyses the conjoint choice of crop mix, irrigation level, technology and employment as an optimization problem and the problem is cast as constraint maximization and solved using mathematical programming techniques (MPT)[3]. This methodology was applied in the EU research project aimed to assess the sustainability of irrigated agriculture in the EU (WADI), in this context the program was developed and tested. DSIRR presents some interesting innovative features.

A first aspect which deserves attention is the presence of a Graphical User Interface (GUI) and the definition of standardized dataset which can be distributed. This makes DSIRR a scenario manager for predefined agro-economic behavioral models. The present beta non commercial demo version operates as a 32 bit Windows application. A modular structure enables a continuous development of the program which can be easily linked to other models. For more information see Bazzani and Rosselli Del Turco (2003).

A second aspect of interest is represented by the accurate description of the agricultural production and irrigation processes.

- Agricultural practices and technologies are described on the basis of an input-output approach. Agronomic, financial, commercial, policy aspects are included. Different types of soil, seasonality, market conditions can be described.
- Water supply is defined at farm gate distinctly for periods and supply systems considering different provision levels. This permits to analyze different tariff schemes.
- Irrigation techniques are described on the basis of efficiency, energy and labour requirements, investment and operative costs and the surface covered.
- Water-yield functions quantify the crop response to water in terms of production quantity[4] , their inclusion permits to identify the efficient irrigation volume by crop and type of soil on the basis of the decreasing marginal productivity of the resource.

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[2] Elasticity is an index which reveals how the demand is responsive to price change.

[3] The models are solved using GAMS (General Algebraic Modelling System) (Brooke, 1992).

[4] Functions are derived via experimental research or other models.

- Water demand is quantified by periods on the basis of crop irrigation requirements, rain and water tableau level.

The user can decide case by case what is relevant and which aspects include. This option, introducing a great flexibility, makes the tool suitable for different situations.

A third aspect deals with scale. A decomposition approach is adopted to reach the level adequate to the problem at hand. The spatial scale can be defined to describe in sufficient detail the complexity of the reality. Different types of farms, describing coexisting production systems (e.g. annual and perennial crops, family and industrial farms, etc.), can be modeled and aggregated at basin scale.

Scenario analysis is adopted to explore different states of the world related to macro-economic and/or climate conditions. Their use permits to deal with uncertainty in a practical way.

The user can run the simulations without any specific knowledge of MPT and modelling thanks to the GUI, while some expertise in agriculture and economics is requested. Utilities permit to access and modify internal databases, view reports and tables, create charts. The present version can export the results to Excel in table and graphical form. Interfacing with other models and programs is easy. Standard output includes: land use (i.e. crop mix), agricultural practices, irrigation technologies and volumes plus a rich set of indicators. A first subset collects economic information covering private and public dimension (e.g. farm net income, contribution to GDP, etc.) A second deals with employment as social indicator (e.g. family and external labor). A third assesses environmental pressures deriving from agriculture: (e.g. nitrate, chemicals, soil covering). Trade-off among conflicting objectives can be easily derived.

4.3 The mathematical model of the farm

Mono and multicriteria approaches are both available to represent the farmer's decision process. In the former case the farmer acts as a profit maximizer, in the latter case the farmer's objective function is composed of different components according to Multi Attribute Utility Theory (MAUT). The aggregate utility function assumed linear (1) requires normalization since different units are involved:

$$U=\sum_{o} w_o * \frac{Z_o^+ - Z_o}{Z_o^+ - Z_o^-} \qquad (1)$$

where: U represents the utility index, Z, Z^+, Z^- objectives values, ideal and nadir (*ideal* and *nadir* are respectively the best and worst case), w weights, o objectives.

The selection of objectives and the estimate of the related weights can be derived via an interactive procedure with the decision makers, or via a non-interactive methodology proposed by Sumpsi et al. (1996), that minimizes the model results distance from observed farmers' choices in a weighted goal programming. Income, risk, labour, technical difficulty can all be considered as possible attributes.

In general the farmer's problem is cast as a constraint maximization and in the simpler case can be formalized as[5]:

$$\max_{\{X,W\}} \mathrm{INC}= \sum_{c}\sum_{i}\sum_{s}\left\{X_{c,i,s}\left[p_{c,i}\, q_{c,i,s}\left(wr_{c,i,s}\right)+su_{c}-vc_{c,i,s}\right]\right\} \qquad (2)$$

$$-\sum_{k}\sum_{l}\sum_{p} W_{k,l,p}\, wp_{k,l,p}$$

subject to:

…

$$\sum_{s}\sum_{c}\sum_{i} X_{c,i,s}\, ir_{c,i,s} \le \sum_{l} W_{k,l,p} \quad \forall k,p \qquad (3)$$

…

where the indices represent: c crop, i irrigation level, s type of soil, k water source, l water provision level[6], p period. To better readability variables, endogenously determined, are written in capital letters to distinguish from parameters ,exogenously fixed. Symbols are: INC income (€), $X_{c,i,s}$ activities[7] (ha), $p_{c,i}$ crop market price (€/t), $q_{c,i,s}(wr_{c,i,s})$ crop production as function of water (t), $wr_{c,i,s}$ crop water requirements (m^3), su_c subsidies (€), $vc_{c,i,s}$ variable costs (€), $W_{k,l,p}$ water consumption (m^3), $wp_{k,l,p}$ water price (€/m^3), $ir_{c,i,s}$ crop irrigation requirements (m^3).

In equation 2, representing the farmers' income objective function, production q is expressed as a function of water and irrigation costs are kept apart. This approach permits the derivation of *water demand function* (4) via parametrization of price or quantity.

$$W = f\left(wp;Q\right) \qquad (4)$$

The function determines the quantity of water W demanded in a given district in a certain period as an inverse function of its price wp, given the farm production possibilities and characteristics Q. An upper limit is imposed on W to control water availability.

5 A CASE STUDY

The case study here presented considers a pricing policy in the Po Basin, the largest irrigated plain area in Italy, characterized by cold winters and hot

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[5] This simplified formulation permits to appreciate the logic of the model. For a more complete presentation of the program see Bazzani (2004), IBIMET - Technical paper, in progress.

[6] Water provision levels permit to simulate an increasing pricing scheme, via blocked tariffs.

[7] An activity is a crop characterized by its production process, i.e. fertilization, irrigation, …; the same crop determines distinct activities if more production possibilities are considered.

summers. The analysis compares two important cropping systems: the annual extensive (AE) and intensive fruit (IF) which coexist in the region. Two agricultural regimes are analyzed: the existing CAP (A2000) and the incoming Mid Term Review (MTR). Under the current A2000, at the prevailing zero cost of water the observed crop mix is mainly given by maize, sugar beet, and soy been, all full irrigated, plus the set-aside requirement. The prevailing irrigation technique is represented by self moving gun. Calibrated the model to this situation, simulations were conducted for the two CAP regimes. Figure 2 shows water demand (WD) and farm net income (NI) for the AE system in the water price (WP) range 0-20[8]. Consumption is on the right vertical axe, NI on the left one.

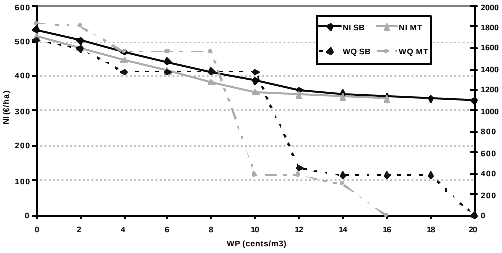

Figure 1. Water pricing on annual crops

Rising of the WP determines three interlink adaptations regarding: crop mix, crop irrigation levels, irrigation technology, which represent endogenous variables of the models. A WP around 8/10 cent €/m^3 splits the demand curves (dotted lines) into two regions. Maize characterizes the first region with low WP but in the second leaves the field to rain fed wheat, this determines a sharp drop in the water demand. The smaller jumps along the curve are due to the progressive decrease of crops irrigation levels. Water consumption becomes null at a WP of 20 cent €/m^3 under A2000. The impact of the MTR reduces WD in the first region, but has an opposite effect at higher prices. This depends on the relatively higher profitability of sugar beet which takes advantage of decoupled subsidies. The water saving is not at zero cost. The negative impact on NI can be visualized on the left vertical axe by the continuous lines. Under A2000 income decreases from 534 €/ha at zero price to 387 €/ha at WP 10 cent €/m^3 and to 329 €/ha at 20 cent €/m^3. MTR function presents a similar pattern but lower values of about 5%. Water agency revenue (WAR) has a maximum at WP 8 cent €/m^3 where the entire surface is irrigated. Higher WP reduces WAR due to the reduced water consumption, this has important implication for cost recovery. Table 1 reports for EA the main indicators for three price levels: the current situation (WP=0), a medium (WP=10) and a high price (WP=20).

PW	NI	SU	GDP	FL	NIT	PES	SPR	WQ
Base								
0	534	340	1018	16	54	5068	0.44	1674
10	387	340	871	15	52	4838	0.42	1372
20	329	340	784	10	37	3849	0.30	0
Mid Term Reform								
0	516	340	1003	18	64	5124	0.45	1838
10	354	340	841	12	44	4135	0.32	386
16	335	340	789	11	43	3863	0.29	0

Table 1. Annual crops system indicators

Subsidy (SU) keeps stable, since the per hectare value is in the region the same for irrigated maize and rain-fed wheat. GDP contribution and employment decrease. Environmental indicators show a more articulated pattern. Nitrates (NIT) and pesticides (PES) reveal decreasing pressures due to the extensivation process, which also determines a soil cover negative trend.

The second production system analyzed is the fruit one which is relevant for added value and employment. Figure 3 presents the impact of the same pricing policy on IF, format is unchanged.

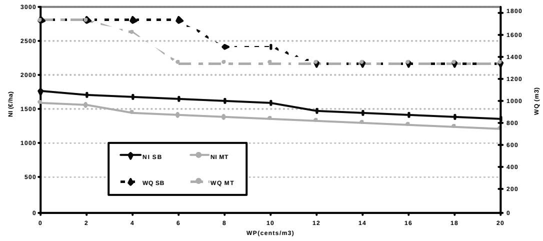

Figure 2. Water pricing on fruit system

The water demand curves show now a completely different pattern mainly in the second region (WP>10 cent €/m^3) which is completely inelastic and stable at over 1300 m^3/ha. This pattern depends on the higher marginal productivity of water in this system which is also captured by the economic indicators (NI and GDP). The reduced irrigation volume for a fruit system is due to the high efficiency of microirrigation largely adopted. Other important differences emerge in Table 2 presenting the IF indicators.

PW	NI	SU	GDP	FL	NIT	PES	SPR	WQ
Base								
0	1754	44	3985	216	69	48656	0.86	1723
10	1586	44	3789	216	69	48507	0.86	1485
20	1371	51	3432	216	67	48811	0.84	1339
Pac Reform								
0	1447	44	3667	216	67	48984	0.84	1615
10	1298	44	3481	216	67	48811	0.84	1339
20	1164	44	3347	216	67	48811	0.84	1339

Table 2. Fruit system indicators

Again most of the indexes show a decreasing trend in both scenario, but the magnitude are clearly

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[8] All the figures describe main trends and should be interpreted more as probable path than exact numbers.

much higher, confirming the intensity of the agricultural process.

Comparing the results significant differences emerge. This information is relevant to design an efficient and effective water policy in the Basin.

6 CONCLUSIONS

DSIRR is an innovative program aimed to support water policy in agriculture via simulation behavioral models, integrating micro analysis at farm level with macro analysis at catchment scale.

A Graphical User Interface permits a direct control of the simulation by the user; this feature along with flexibility, transparency and replicability, makes the tool suitable for a participative decision process. The integration of agronomic, engineering and economic aspects guarantee a good level of detail in the analysis. Farmer's preferences are described following a multicriterial methodology which permits to integrate into the process stakeholders' perspectives.

The case study illustrated how the tool can be used to assess ex-ante the feasibility of a pricing policy in agriculture. Results point out that in the same Basin coexisting cropping systems exhibit very difference responses. In fact, while annual crops are quite sensible to a water price increase, fruit has a much more inelastic response. A pricing policy could therefore have positive effects in terms of water saving in the former but would result quite ineffective on the latter. A reduction of environmental pressures coming from agriculture is assessed but following a sensible contraction of farm income and agricultural employments. The impact of the new CAP reform decoupling subsidies from production and introducing eco-sussidiarity seems to favor environmental objectives at expense of farm income and employment. A trade off among conflicting environmental, socio and economic objectives emerges which the analysis can quantify leaving to the political process the final decision.

DSIRR represents a practical and operational approach that could be applied by practitioners, dealing with the development of integrated river basin management plans, to assess ex-ante the effectiveness of individual and of combination of measures, when water use in agriculture were relevant. In fact it represents a bridge between science and policy, making operational economic methodologies and approaches. For its characteristics the program can be a useful tool to support discussion between experts and stakeholders about alternative measures. This aspect is possibly more important than its exact predictions. Stakeholders integration into the economic analysis brings expertise and information, it provides opportunities to discuss and validate key assumptions and finally it increases the ownership and acceptance of the results of the analysis. Hopefully, the program implementation in the next future will help to develop practical experience, will increase the knowledge base and will develop capacity in the integration of economics into water management and policy, favoring balanced solutions capable to achieve good water status in an efficient way with acceptable social impacts.

7 REFERENCES

Bazzani G., Di Pasquale S., Gallerani V., Morganti S., Raggi M. E Viaggi D. (in print) The impact of EU water framework directive on irrigated agriculture in Italy: the case of the north east fruit district. *Agricultural Economic Review*.

Bazzani, G., Rosselli Del Turco ,C., 2003. DSIRR: a Decision Support System for Irrigation and Water Policy Design, in "Water management", Brebbia C.A. Ed., WIT Press, Southampton-Boston, pp. 289-298.

Berbel, J., Rodriguez, A.A., 1998. MCDM approach to production analysis: an application to irrigated farms in Southern Spain. *European Journal of Operational Research* 107, 108-118.

Brooke, A., Kendrick, D., Meeraus, A., 1992. GAMS A user's guide. The Scientific Press.

European Council Directive 2000/60 Establishing a Framework for Community Action in the Field of Water Policy.

Gómez-Limón, J.A., Arriaza, M., 2000. Socio-Economic and Environmental Impact of Agenda 2000 and Alternative Policy Choices for Market Liberalisation on an Irrigated Area In North-Western Spain. *Agric. Economics Review* 1, 18-30.

Gómez-Limón, J.A., Arriaza, M., Berbel J., 2002. Conflicting Implementation of Agricultural and Water Policy in Irrigated Areas in the EU. *J. of Agric. Economics* 53, 259-281.

Joahansson R. C., Tsur Y., Roe T.L., Doukkali R., Dinar A., 2002. Pricing irrigation water: a review of theory and practice. *Water Policy*. 4, 174-199.

Sumpsi, J.M., Amador, F., Romero, C., 1996. On farmers' objectives: A multi-criteria approach. European Journal of Operational Research 96, 64-71

Varela-Ortega, C., Sumpsi, J. M., Garrido, A., Blanco, M., Iglesias, E., 1998. Water Pricing Policies, Public Decision Making and Farmers response: Implications for Water Policy. *American Journal of Agricultural Economics* 19, 193-202.

Ward F.A., Michelsen A., 2002. The economic value of water in agriculture: concepts and policy applications. *Water policy* 4, 423-446.