Pricing irrigation water under asymmetric information and cost recovery constraints

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Abstract The objective of this paper is to discuss how policy makers may deal with irrigation water pricing under asymmetric information, positive transaction costs on payments and cost recovery constraints. The issue is dealt with through the development of a principal agent model and its application to a pilot case study in Emilia Romagna, Italy. The results show that using a menu of contracts may improve the overall social welfare derived from irrigation. However, differences in performance among instruments (and hence the choice of the optimal pricing strategy) are critically determined by the amount of the full cost of water and of transaction costs. Moreover, differentiation among farmers may encounter policy obstacles as a potential source of conflicts.

Keywords Agriculture; asymmetric information; contracts; irrigation; principal-agent; water pricing

Introduction and objectives
A widening discussion is developing in the EU about the application of the 60/200/EC Water Framework Directive (WFD). Among debated issues, the economic aspects of the WFD, in particular cost recovery and water pricing, play a major role (WATECO, 2003). One of the main issues in agriculture is that the absence of water metering hampers the possibility of volumetric pricing and possibly of using cost recovery as an incentive for the reduction of water use. The issue is common for most agricultural water use worldwide (Dinar and Subramanian, 1997; Tsur et al., 2002; Johansson et al., 2002).

One possible option is to tackle the problem the hard way, by imposing metering whenever water is used. However, this would possibly imply very high costs, which often may not be justified in terms of cost effectiveness, as farmers (the final users) could not be able to pay for such costs. A softer way is to attempt to design contracts able to discriminate among farmers so as to encourage them to use the “right” amount of water. This option may entail economic advantages as well as normative difficulties as it is not supported by the legal system of many countries, among which Italy. However, even the economic rationale does not necessarily lead to a preference for mechanism design, as long as incentive costs are to be taken into account.

The objective of this paper is to discuss how policy makers may deal with water pricing under asymmetric information and positive transaction costs on payments, when, in addition, cost recovery is introduced. The paper builds on a principal agent model and its application to a pilot case study in Emilia Romagna, Italy. The paper outline is the following. In section 2 (following this introduction), an overview of contract design issues related to irrigation water pricing is provided, with specific reference to Italy. Section 3 describes the methodology adopted, followed, in section 4, by the results of a case study. Finally, some discussion is provided in section 5.

Overview of the WFD and water pricing issues in agriculture
The WFD provides a general framework for water regulation in Europe. The application is intended to be differentiated at local level, according to river basin organisations. The
implementation will go through a number of steps and should be completed by 2012 (WATECO, 2003). The WFD identifies some major economic criteria common for all countries. The first is the principle of Full Cost Recovery (FCR). According to this principle, the user of water should bear all the costs of water provision. The second major principle introduced is the Polluter Pays Principle (PPP). According to the PPP, water users should bear the environmental costs of water abstraction as well as the financial and the opportunity costs of water provision. Both principles may be relaxed in practice. In particular, according to EU documentation, the cost recovery does not need to be “full”, if such derogation may be justified by economic, social or environmental reasons.

From an agricultural perspective, this could mean a net increase of water prices. In Italy, for example, only operational costs for water provision are borne by the final users. A major issue, however, is how to apply any cost recovery principles or provide any incentive to farmers when water use is unmetered. This is a common condition of most farming systems in Italy. The solution may be found in the creation of a metering system that, however, implies costs, sometimes very high in terms of infrastructures or in terms of personnel and enforcement. Alternatively, contract systems may be designed in order to deal with the problem. For example, when the production function of each farmer is known, payments may be indirectly connected to a computed use of water. Another issue to be dealt with is the relevance of transaction costs faced by both water distribution bodies and farmers (McCann and Easter, 2002). Transaction costs may concern search, negotiation, monitoring and enforcement of contracts. In the case of water they may be connected to negotiation for contract design, water quota measurement and enforcement, charges collection, disputes over payments, etc. Incentive costs, i.e. deadweight losses due to asymmetric information of incentive payments, may add to direct transaction costs. In spite of the wide perception of their potential relevance for pricing and contract design, the literature about their importance and impact on optimal water regulation is relatively poor.

In many cases, however, both the production function of single farmers and the amount of water used are unknown. In addition, when positive transaction costs arise from money transfers, mechanism design may be required in order to identify contracts able to encourage farmers to self qualify. This approach is gaining attention for a number of issues where asymmetric information is relevant (Salanié, 1998; Laffont and Martimort, 2002). However, in spite of the relevance of the problem for water management in agriculture, only a few examples exist about the application of such concepts to irrigation water (Smith and Tsur, 1997; Tsur, 2000; Bazzani et al., 2004).

Methodology
The setting
The methodology is based on the use of contract theory as a tool for the evaluation of possible improvements in water pricing of unmetered water. The setting is that of a regulator willing to induce farmers to use the socially optimal amount of water. Under perfect information (first best), the regulator knows all relevant pieces of information and can attribute to each farmer the optimal water quota and assign the optimal payment, if required. Under asymmetric information, the regulator knows the existence of different farm types and their characteristics, but cannot tell to which type each single farm belongs.

In order to regulate water use, the regulator may use different policy instruments. Those considered in this paper are a menu of contracts (produced using mechanism design) and an area payment. Each contract in the menu is defined by a combination of a payment ($p$) and a required level of a control variable ($q$) related to water use. Below,
the control variable considered will be the irrigated area. Area payments are based on an equal distribution of total FC on the whole area, irrespective of the amount of water used and of the share of irrigated land.

These three options (first best, menu of contracts and area payments) are evaluated with or without a FCR constraint aimed at ensuring that costs for water provision are fully recovered. In the first best and in the menu of contracts, the FCR constraint guarantees an individual FC. In the area payment, as the instrument does not allow to distinguish among farm types, only a global FCR constraint is assumed. Additionally, we assume that once a quota is assigned to a single farm, whatever the instrument used, the contract is perfectly enforceable.

The model without budget constraint
We assume the existence of two farm types \( (i = 1, 2) \) with different productivity of water and, as a consequence, a different profit produced by the change in the quota of irrigated land assigned (farm type 1 is more efficient and farm type 2 is less efficient). We assume that farms’ profit function with respect to the irrigable area \( \pi() \) is concave with \( \pi'() < 0 \) and \( \pi''() \geq 0 \), while farms’ water use function with respect to the irrigable area \( w() \) is convex, with \( w'() > 0 \) and \( w''() \geq 0 \). We also assume that the full cost of water provision \( v() \) is linear with respect to the amount of water used and the transaction costs are proportional to the payment requested. The latter assumption may appear an oversimplification of reality. However, it is rather common in the literature and allows to get an idea of the role of transaction costs while keeping the model relatively simple.

Taking into account the assumptions above, the objective function of the decision maker (2) can be written as:

\[
\text{max } z_i(q_i, p_i) = \gamma[-vw_1(q_1) + \pi_1(q_1) - \tau p_i] + (1 - \gamma)[-vw_2(q_2) + \pi_2(q_2) - \tau p_2] 
\]

where,

- \( p_i \): payment requested to farmer \( i \),
- \( q_i \): amount of irrigable land allocated to farmer \( i \),
- \( \tau \): transaction costs connected to payment and
- \( \gamma \): subjective prior probability that the regulator assigns to the farm being of type 1 (quantified, for example, on the basis of the total land expected to belong to farm type 1).

In this setting, the regulator wishes to maximise the social welfare represented by farm profit minus the cost of water provision, minus the transaction costs connected to the collection of payments from farmers.

In the first best conditions, under perfect information, the objective function may be separated for the two farm types and the problem of the regulator may be written as:

\[
\text{max } z_i(q_i, p_i) = -vw_i(q_i) + \pi_i(q_i) - \tau p_i \quad \text{s.t.: } PC_i : \pi_i(q_i) - p_i \geq 0 
\]

where \( z_i \) is the objective function of the decision maker related to farmer \( i \). Complementary conditions are that \( p_i \) and \( q_i \neq 0 \) and \( \tau > 0 \).

\( PC \) is the acronym of Participation Constraints. They ensure that it is not possible to ask farmers for more money than their profit from water use. In the first best assumptions, the optimal solution (amount of \( q \) to be attributed to each farm) is given for each farm by:

\[
vw_i'(q_i) = \pi'_i(q_i)
\]

In addition, it would be optimal to regulate water use without any transfer, as any payment has a cost determined by \( \tau \). In the second best, mechanism design is applied
following the objective function (1) and the constraints below:

\[
\begin{align*}
PC_i : \pi_i(q_i) - p_i & \geq 0 \\
IC_1 : \pi_1(q_1) - p_1 & \geq \pi_1(q_2) - p_2 \\
IC_2 : \pi_2(q_2) - p_2 & \geq \pi_1(q_1) - p_1
\end{align*}
\] (4)

where IC, Incentive Constraints, ensures that each type of farm will find it profitable to choose the contract that is designed for it. In this case, the optimal contract design produces a menu of contracts differentiated with respect to the farm type to which they are addressed. By assumption about the shape of the profit functions, farmer 1 has no incentive to disguise himself as farmer 2. Instead, farmer 2 has an incentive to falsely report to be a type 1 farmer. If only IC2 holds, then the payments are determined by:

\[
\begin{align*}
p_1^a = & \pi_2(q_1^a) - \pi_2(q_2^a) \\
p_2^a = & 0
\end{align*}
\] (5)

where the superscript \(a\) is a reminder for “asymmetric information”.

The optimal amount of irrigable land to be assigned to farmers type 1 and 2 is determined respectively by:

\[
\begin{align*}
vw_1'(q_1^f) & = \pi_1'(q_1^f) - \tau(\pi_2'(q_1^f)) \\
vw_2'(q_2^f) & = \left(1 + \frac{\gamma}{1 - \gamma}\right) \pi_2'(q_2^f)
\end{align*}
\] (6)

This entails a reduction of the amount of water used by the most efficient farmer, and a shift towards a higher use of water by the least efficient farmer, such shift being justified by the need to reduce the transaction cost of payments.

In the case of a flat rate payment per unit of land, in the absence of FCR constraint, each farmer tends to maximise his profit by choosing an amount of irrigable surface such that \(\pi_i'(q_i^f) = 0\) (where \(f\) is a reminder for flat rate), while the regulator asks no payment in order not to incur transaction costs. The single farmer has no incentive to use less water (as the payment is fixed) and sets the irrigated surface and the water use at his private optimum.

**The model with FCR constraint**

Adding a budget constraint put an additional constraint on the model and may be expected to reduce the value of the objective function. However, the effect is different depending on the policy instrument considered. In the case of the first best and mechanism design, the FCR constraint is specified as:

\[
p_i \geq vw_i(q_i) + \tau p_i
\] (7)

Since \(p_i\) is always binding, the amount of payments determined is:

\[
p_i = \frac{vw_i(q_i)}{1 - \tau}
\] (8)

By substituting in the objective function and taking first order conditions yields:

\[
vw_i'(q_i) = (1 - \tau)\pi_i'(q_i)
\] (9)

that entails a reduction of the amount of water used for both types with respect to the model with no FCR constraint. The reduction is due to the fact that the regulator tries to
collect enough payments, while saving on the transaction costs. In the case of the menu of contracts, the same constraints affect the result in a different way depending on which IC is binding. When IC1 is binding, \( q_1 \) is the same as in the first best, while \( q_2 \) is given by:

\[
vw'_2(q_2) = \frac{1 - \tau}{1 - \gamma(1 - \tau)} [(1 - \gamma)\pi'_2(q'_2) - \gamma\tau\pi'_1(q'_2)]
\]  

(10)

When IC2 is binding, \( q_2 \) is the same as without FCR constraint, while \( q_1 \) is given, in analogy as before, by:

\[
vw'_1(q'_1) = \frac{1 - \tau}{\tau + \gamma(1 - \tau)} [\gamma\pi'_1(q'_1) - (1 - \gamma)\tau\pi'_2(q'_1)]
\]  

(11)

The result is a further reduction of optimal amount of irrigable surface.

Finally, in the case of flat rate payment, the optimal private amount of irrigated surface is the same with and without FCR. However, when a FCR constraint is introduced, the payment becomes positive and is determined by:

\[
pf = \frac{1}{1 - \tau} \left[ \gamma(vw'_1(q'_1)) + (1 - \gamma)(vw'_2(q'_2)) \right]
\]  

(12)

**Construction of the profit functions**

A major issue common to the majority of these models is the estimation of the demand for water and the profit as a function of the control variable. The most common approaches are based on production functions or land quality indexes. However, these approaches do not take into account the relevance of rotation and substitution possibilities between crops and the ability of different farmers in gaining and maintaining market shares for specific products, nor the shift of land among farmers. In order to take into account such issues altogether, in this paper, such a task has been performed by using mathematical programming. In particular, linear programming is used, with the following standard mathematical formulation:

\[
\text{max } GM = \sum_{k=1}^{n} gm_k x_k
\]  

s.t. : \( \sum_{k=1}^{n} a_{hk} x_k = b_h \) for \( h = 1, \ldots, m \) \( x_k \geq 0 \) for \( k = 1, \ldots, n \)

where \( GM \): total gross margin, \( gm_k \): gross margin per unit of production process \( k \), \( b_h \): total availability of factor \( h \), \( a_{hk} \): quantity of factor \( h \) necessary to activate one unit of production process \( k \), and \( x_k \): level of activation of production process \( k \).

The constraints considered include land availability, labour availability, crop rotation and commercial constraints. Linear programming models may be used in order to manage the relationships among production processes and may be a good simulation tool for the analysis of economic-environmental issues connected to water use (Gallerani et al., 2004; Berbel and Gutiérrez, 2005). In this paper, different linear programming models have been constructed for relevant farm types. For each one, the water demand and the profit as a function of the control variable have been calculated by parametrising on a constraint that forces the model to a certain quota of irrigated land. In order to fit with the properties of the cost function required by the principal-agent model, the resulting supply curve has been smoothed by finding the interpolate of the points produced by the model.
Results of a case study in Emilia Romagna

The case study area

The models are tested in the Commune of Mirandola, Emilia Romagna, Northern Italy. The area is characterised by a water distribution system based on open canals. Agriculture in the area is mostly characterised by extensive crops, such as wheat, sugar beet, maize, soy bean. In addition, some farms are specialised in melon. Data for the construction of the linear programming model are drawn from the recent (2000) census and seven on-farm questionnaires. Census data provide information about the crops cultivated, the main techno-economic orientation and the farm structure. Two farm types were identified. The distinction is based on the different ability to engage in the production of vegetables, mostly melon. This difference translates into a larger or tighter productivity of the allowed irrigable surface. Table 1 summarizes the main features of the two farm models.

On the basis of data arising from the balance sheet of some irrigation boards, transaction costs ($\tau$) have been set at 10% of the total payments and assumed to be equal across farm types. In order to make results comparable, all data are given per 1 hectare.

Optimal contracts

The results for a full cost of water ($v$) equal to 0.20 €/m³ show moderate differences among policy options (Table 2).

The introduction of FCR constraints causes a decrease of social welfare in the range of 30–40 €/ha. Different policy options within FCR and within No FCR show differences in the order of 1–3 €/ha, that appear substantially negligible. For lower values of $v$, the differences may be expected to be even less relevant. On the contrary, the different policy options yield rather different results when $v$ increases (Table 3).

The introduction of FCR causes a loss of social welfare of about 6 to 60 €/ha. In proportion to the total social welfare obtainable under $v = 0.30$ €/m³, this is about 10 to 70%. Under this assumption, the differences among policy instruments under the same FCR conditions become stronger. In particular, second best menus of contract perform close to the first best. The loss of welfare of the flat rate option in comparison to the menu is about 20% in the case of no FCR and close to 70% in the case of FCR.

<table>
<thead>
<tr>
<th>Farm type</th>
<th>Probability ($g$)</th>
<th>Profit function</th>
<th>Water use function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type 1 (vegetables)</td>
<td>0.26</td>
<td>$\pi(q) = 2,552.2 q - 16,561 q^2$</td>
<td>$w(q) = 3,775.8 q - 18,715 q^2$</td>
</tr>
<tr>
<td>Type 2 (no vegetables)</td>
<td>0.74</td>
<td>$\pi(q) = 816.21 q - 5,5787 q^2$</td>
<td>$w(q) = 2,866.3 q - 18,369 q^2$</td>
</tr>
</tbody>
</table>

| Table 2 Results of different policy options ($v = 0.20$ €/m³) |
|-------------------|-------------------|-------------------|
| $q$ | $p$ (€/ha) | $z$ (€/ha) |
| Type 1 | Type 2 | Type 1 | Type 2 |
| No FCR | First best | 0.701 | 0.638 | 0 | 0 | 221.08 |
| Second best menu | 0.699 | 0.647 | 3.47 | 0 | 220.98 |
| Second best flat rate | 0.771 | 0.732 | 0 | 0 | 218.23 |
| FCR | First best | 0.691 | 0.599 | 381.13 | 235.05 | 193.53 |
| Second best menu | 0.691 | 0.429 | 381.13 | 198 | 190.32 |
| Second best flat rate | 0.771 | 0.732 | 399.60 | 399.60 | 178.26 |
Sensitivity analysis

A sensitivity analysis on $\tau$ and $v$ has been conducted in order to check the potential impact of different transaction costs and water full costs in the case of FCR constraints model (Figure 1).

Transaction costs have almost no effect when the water full cost is very low, while their impact becomes more evident for higher values (slope of the functions). The shift from flat rate payments to contracts has almost a negligible impact for low cost of water, while it increases dramatically for the higher full cost hypothesized. For high transaction costs combined to high full cost of water the difference between policy instruments in presence of full cost recovery becomes a major issue, in order to guarantee the social profitability of irrigation.

Conclusions

The results show that using a menu of contracts may improve the overall social welfare derived from irrigation water use, when there are asymmetric information and transaction costs. However, there are conditions under which such benefits are negligible or null, and others when efficiency improvements due to more refined policy instruments may be crucial. In this perspective, the actual social cost of water plays a critical role not just in defining optimal payment levels, but also in affecting the choice of the right policy instrument. In addition, any proposed change in the policy instrument must be evaluated

Table 3 Results of different policy options ($v = 0.30$ €/$m^3$)

<table>
<thead>
<tr>
<th></th>
<th>$q$</th>
<th>$p$ (€/ha)</th>
<th>$z$ (€/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Type 1</td>
<td>Type 2</td>
<td>Type 1</td>
</tr>
<tr>
<td>No FCR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First best</td>
<td>0.648</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Second best menu</td>
<td>0.644</td>
<td>0</td>
<td>294.26</td>
</tr>
<tr>
<td>Second best flat rate</td>
<td>0.771</td>
<td>0.732</td>
<td>0</td>
</tr>
<tr>
<td>FCR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First best</td>
<td>0.627</td>
<td>0</td>
<td>543.70</td>
</tr>
<tr>
<td>Second best menu</td>
<td>0.627</td>
<td>0</td>
<td>543.70</td>
</tr>
<tr>
<td>Second best flat rate</td>
<td>0.771</td>
<td>0.732</td>
<td>599.41</td>
</tr>
</tbody>
</table>

Figure 1 Social welfare under different levels of transaction costs and full cost of water ($v = 0.30$ €/$m^3$)
against the actual institutional context, where no actor has incentives to act as the benevolent regulator assumed in the model. Additionally, local administration and irrigation boards encounter resistances in creating any differentiation among farmers, as it is viewed as a source of conflicts.

A number of possible extensions may be devised for this paper. First of all, other policy/water distribution instruments may be taken into account. For example, a comparison with the cost of infrastructures required to allow water metering and pricing could be carried out. The structure and the role of transaction costs should also be further understood: are they proportional to payments, proportional to the number of paying farms, fixed, mixed? A particular issue is monitoring and enforcement costs and how they change in the different hypotheses of water regulation. Also, the profit function arising from linear programming may be used as such, without smoothing. Moreover, more farm types or even continuous farm types could be used, possibly crossing soil characteristics and marketing constraints. Sensitivity of the results to scenarios concerning prices and other parameters may be also estimated.

References