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TITOLO TESI

The design of pricing policies for the management of water resources in agriculture under asymmetric information

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Dedication

In memory of my father Muhamet Lika

Abstract

The pricing method mostly adopted by water authorities (WAs) supplying water for irrigation through surface irrigation networks is the flat rate. This scheme violate either the Water Framework Directive (WFD) Incentive Pricing Principle (IPP) and Polluter Pays Principles (PPP), not providing incentives for efficient water uses and disregarding differences in irrigation water use among farmers. The use of flat rates is justified by the fact that monitoring water uses is too costly and even not effective, as WAs operate in conditions of hidden information. Under such conditions, by being unable to monitor water use, farmers have an information advantage against the WA. This fact exposes the WA to suffer a 'pricing failure' if it decides to apply an incentive pricing strategy (tariffs proportional to the alleged water uses). Indeed, farmers might exploit their information advantage behaving in an opportunistic way withdrawing more water than declared and finally paying less than they should. This would undermine the effectiveness and the efficiency of the WA's pricing strategies.

By means of contract theory in this thesis four goals are set:

The first one is to theoretically assess an incentive pricing schemes for surface irrigation networks under conditions of lack of information. I adopted a principal-agent approach for explaining difficulties experienced by European WAs operating in the agricultural domain to comply with water legislation in the absence of water metering. It is shown that discrimination policies might result in an efficient tool for the management of the water resource. Thought from the analysis it is understood that diverse characteristics of farm types (i.e. profits and costs) lead to different contracts solutions and drive the WA to use different strategies to incentivize farmers to behave truthfully, might be concluded that pricing strategies are highly linked with water users characteristic and its application varies with the irrigation networks.

The second goal is to define an efficient pricing scheme for irrigation water in conditions of unmetered water use. The study identifies a menu of contracts defined as a set of payments and share of irrigated area able to provide incentives for an efficient use of the resource by maximizing social welfare. The model is applied in a case study of the Çukas region (Albania) where irrigation water is not metered. The results illustrate that using a menu of contracts makes it possible to define the second best solution that may improve the overall social welfare derived from irrigation water use compared with the existing pricing structure flat rates, though, in the specific case study, the improvement is small. Furthermore, the results suggest that irrigation water pricing policy needs to take into account different farm types and that appropriate contract-type pricing schemes have a potential role in providing incentives to farmers to make irrigation choices to the social optimum.

The third goal is to investigate an incentive water pricing policy by introducing a monitoring strategy that enables the WA to detect farms behaviour with the water resource. In doing so the incentive strategy is compared with the flat rate water pricing and is assessed under what conditions the WA might provide/not provide incentive water pricing in the absence of water metering. The numerical example demonstrates that when the level of water costs and transaction costs are preclusive, an adaptation of incentive water pricing is limited. In addition, is shown that only above a certain threshold level of monitoring probabilities (with respect to water supply costs and transaction costs) social benefits are higher under incentive water pricing than the flat rate instrument.

The fourth goal of the thesis is to analyse a pricing strategy under the problem of moral hazard where monitoring costs are function of monitoring efforts. Under this assumption, the empirical evidences show that, if the probability of detecting the noncompliant farmer is function of monitoring intensity, the maximization of social benefits is achieved when the level of monitoring is not maximized and there is a trade-off between monitoring intensity and efficiency gain by monitoring.

In addition, the thesis illustrates how asymmetry of information and transaction costs drive the WA to propose a less efficient contract solution due the rent extraction needed to reveal farms' private information and guaranteeing the implementation of the pricing strategy. The main conclusion arising from this research turns to be that; the implementation of a pricing strategy depends upon the context surrounding the irrigation network.

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Acronyms

ALL	Albanian LEK
EC	European Commission
EMP	Econometric Mathematical Programming
EU	European Union
FB	First Best
FCR	Full Cost Recovery
FR	Flat Rate
IPP	Incentive Pricing Principle
LP	Linear Programing
O&M	Operation and Maintenance
OECD	Organization for Economic Cooperation and Development
PMP	Positive Mathematical Programming
PPP	Polluted Pays Principle
SB	Second Best
TEV	Total Economic Valuation
WA	Water Authority
WFD	Water Framework Directive
WTP	Willingness To Pay
WUA	Water User Association

Chapter 1

1. Background, Problem Statement, Objectives and Modelling Overview

1.1 Background

Increasing water consumption level and adverse climate change impact are expected to rise the water scarcity, by rising the need for an efficient water allocation system. To this concern, policy makers have called for the regulation of the demand side to stop the loss and overuse of the water resource. In the last 30 years, most developed countries have been undertaking major policy reforms in the water sector. In Europe, the decline in water quantity and quality has urged the European Union (EU) to respond by implementing new policies. Many EU countries have implemented new legislative and frameworks to transpose EU's Water Framework Directive (WFD) into national legislation (Garrido and Calatrava, 2010). Likewise developed countries are promoting strategies that guarantee full cost recovery (i.e. supply costs, economic and resource costs and environmental cost) for irrigated agriculture (Easter and Liu, 2005). Noteworthy, most of the developed countries are following pricing policies toward a full cost recovery but various countries have failed in their strategies to achieve this objective in accordance with the WFD (Toan, 2016; EEA, 2013).

Pricing policies are considered as an important tool for encouraging water users to better manage the scarce water resource and allowing water providers to improve water allocation. Based on this background, water-pricing policies are generally seen as one of the most important tool for water demand management in the context of the over-abstraction of water (Expȯsito and Berbel, 2016). The mechanisms of water pricing are frequently proposed as a strategic instrument for water management, such as in the WDF European Commission, (2000) and the Blueprint to Safeguard Europe's Water.

Over the past decades, scholars have given their contribution with development of pricing policies in theory and practice (Dinar and Subramanian, 1997; Dinar et al 2015; Bournaris et al., 2015; Bartolini et al., 2007). These authors compare and present water-pricing experience across many countries over the word. They realize the need for pricing water volumetrically and introducing incentive tools to affect the behaviour of water users and suppliers. Johansson et al. (2002) provides a comprehensive review of theoretical and practical issues regarding pricing irrigation water. They reviewed various methods of irrigation water and identified the important impact of water pricing policies across countries. Bournaris et al. (2015) addresses some of the most relevant current and perspective issues for water policy. The authors investigate the issue in an economic context for the management of irrigation water for agriculture. In addition, the book offers a wide variety of innovative approaches of water management in European irrigated agriculture. Dinar and Mody (2004) discuss pricing and other complementary economic instruments (incentive strategies) as tools to achieve a more efficient water use. Furthermore, Tsur (2004) emphasizes that demand management should be a central point in planning water pricing policies to promote efficient use of water resource. Hereto, the European Council made recommendations with regard to this issue and water resource sustainability in EU member states (Elnaboulsi, 2009). Also, the European Commission (EC) (2015) report highlights the insufficient implementation of the measures for achieving the environmental objectives of the WFD related to application of transparent water pricing across all member states, mainly due to lack of metering. The EC highlights the need for widespread metering in basins where irrigation is the main water use and implementation of measures are necessary, mainly for Greece and Italy where irrigation is served via surface irrigation networks and per hectare water prices are predominant (ARCADIS, 2012).

Yet, the implementation and the outcomes of such economic tools and incentive strategies are depended on several factors that, often, prevent their effectiveness. Lack of water metering is the main constraint. This condition hinders the ability to monitor volumes used and to promote volumetric pricing as a way to allocate costs and to ensure efficient water use (Viaggi et al., 2010; Galioto et al., 2013; Smith and Tsur, 1997; Lika et al., 2016). The impossibility of applying a volumetric water pricing in irrigation networks where the irrigation water is served through open channels have driven scholars to develop and introduce pricing strategies that are a proxy of volumetric pricing.

However, several difficulties arise while designing these water tariffs. In particular attention is given to the effect of transaction costs and asymmetric information on irrigation water regulation. The transaction costs (in this study) indicate the cost of implementing the water-pricing scheme in the region. Asymmetric information may go under the form of non-observability of farm types and its technology and non-observability of a farm's actions (Galioto et al., 2013).

Smith and Tsur (1997) initially addressed the issue of asymmetric information for irrigation water in the absence of metering. More recently, Gallerani et al. (2005), Viaggi et al. (2010), Galioto et al. (2013) and Lika et al. (2016) investigate how the presence of asymmetric information might affect the way that WAs design their pricing mechanism in some European regions. Asymmetric information for irrigated agriculture appears in two forms: when water authority (WA) is unable to observe farm's characteristic and when the WA is unable to detect farms action. Unmetered irrigation water allow farmers to have private information in water use function (Tsur, 2000) as such, farmer may benefit from taking its action (moral hazard) that allow him to maximize its benefit in spite of what has been agreed in the contract (Latacz-Lohmann, 2005) or when the WA may know the existing farm types, but is unable to observe each farm type belong to whom (Lika et al., 2016).

In line with the above literature which emphasise the need for the development of incentive pricing instruments for irrigated agriculture, this thesis further analyse the pricing policies in order to evaluate the interplay between farms' water tariffs and irrigated share (with respect to farms' profits and costs) under full and asymmetric information conditions.

1.2 Problem statement and motivation

The background provided above shows that in some regions water entities have advanced in designing mechanisms and policy implementations according to the WFD demands, but that such steps leave much to be improved with respect to achieving a sustainable water use. Though different water pricing mechanisms and strategies exist, the question is whether these strategies are worth being implemented, and whether their benefits are tangible in reality when applied to heterogeneous populations or farmers with varying characteristics.

With regard to surface irrigation networks, mostly applied in many regions of Europe but not only (i.e. China, India), WAs face difficulties in reforming water-pricing policies in order to meet demand management. Incentive pricing mechanisms are vague in most countries, and current water pricing systems are often distorted leading to large cases of no incentives for water conservation (Shen and Reddy, 2016). In addition, the obstacles WAs face involve lack of water metering, the presence of asymmetric information between WAs and water users, high level of transaction costs and heterogeneous population of water users complicate the implementation of incentive water pricing. These limitations affecting the applicability of ideal pricing instruments oblige WAs to implement flat rates disregarding any differences in water uses and not incentivizing efficient uses.

With regard to surface irrigation networks water users respond imperfectly to water prices (Garrido and Calatrava, 2010). Their behaviour arise from the fact that uniform tariffs do not provide incentives to efficiently use the water resource by not encouraging users to use the water on the bases of costs they generate and for what they pay for. In line with these concerns, the question is what mechanisms would provide a pricing instrument that guarantee water tariffs based on costs generated by each individual farm. In this respect, the choice of the use of a principal-agent model aims at analyzing the relationship between principal and agent because here is dealt with a case where the water resource is served by the WA (principal) to farmers (agents). In addition, a principal-agent model is widely applied in the field of agriculture economies.

What motivates me to conduct this research is the importance of the investigation and adaptation of incentive economic instruments in function of the management of the irrigation water resource. Although besides the obstacles that impedes the adaptation of incentive instruments its development and implementation is fundamental to guarantee an efficient allocation of the water resource and to accomplish the WFD requirement with regard to water resources. In addition, with this thesis I attempts to shed light in the effectiveness of the implementation of incentive strategies and to identify under what conditions they might be a substitute of uniform flat rate pricing instruments. The analysis and the comparison with flat rate pricing policies (already applied in most of surface irrigation networks) helps to clarify and identify conditions when incentive pricing strategies result more costly-effective policy.

In this respect, the use of incentive pricing strategies from the range of economic instruments is one of possible tools applicable to motivate water users to comply with a particular policy and to improve the use of the water resource. For instance, provision of incentives boost water users to pay water tariffs in function of their water usage, which might contribute in the achievement of a more sustainable water use. In addition provision of price discrimination (when possible) incentivize water users to a more rational water use and drive to lower water supply costs for the WA compare with flat rates. The implementation of these policies would lead not only to the achievement of the cost recovery of the resource provision but also to the achievement of environmental goals (decline environment pollution).

In this regard, while considering the design of incentive pricing policies, the thesis address problems of how the water supply costs are distributed among farms.

1.3 Research objectives

The overall objective of this study is to assess the potential for the use of an incentive water pricing scheme for irrigation water, when irrigation water is unmetered. I evaluate this option considering two related conditions: transaction cost and asymmetric information. In this study, transaction costs are taken to be the costs of implementation and enforcement of the pricing strategy and are distinguished from rents generated from asymmetric information.

The study challenges and discusses the practicability of a tariff design that is able to recover water supply costs and deals with biases in information by WA. Under such circumstances, conditions are assessed in which it makes sense for a regulator to consider implementing incentive pricing mechanisms in a way of maximizing social benefits and incentivizing rational water use.

The specific objectives of the research are:

- to provide a theoretical analysis of incentive water pricing for irrigated agriculture under the problem of adverse selection. The study also aims at identifying conditions affecting the efficiency of pricing strategy;
- to design an efficient (social welfare maximizing) pricing scheme in conditions of unmetered water, using empirical information from a region in Albania;
- to provide an incentive water pricing strategy in the absence of water metering by considering the presence of moral hazard and transaction costs;
- to analyse a pricing strategy under the problem of moral hazard where monitoring costs are function of monitoring efforts.

This research considers several hypothesis under different information basis and is related to the regulation of irrigated agriculture via pricing, when there is an inability of the WA to distinguish farm types and to detect their actions.

Different from most of the literature, a novelty in this thesis is that, the models concerning adverse selection problem count for several assumptions which aim at not only optimizing water supply costs but also considering the profit from the use of water. On the other hand models under moral hazard with regard to irrigated agriculture have not been developed previously. In addition the modelling approach used here tries to capture the impact of pricing strategies arising from information asymmetries and direct transaction costs simultaneously. I also assess optimal monitoring levels and conditions under which implementation of monitoring strategy is economically efficient. Furthermore, I extend the analysis in identifying conditions where incentive water pricing may efficiently replace flat rates in irrigated agriculture.

From the literature is well known that still several countries use flat rate water pricing. Water tariffs are independent of the amount of water delivered. Although water management institutions objectives may be at least partially satisfied, price incentives and water conservation strategies are inexistent or yet not applicable. To this concern, I introduce incentive strategies as a policy mechanism. The focus is to highlight the importance this tool for irrigated agriculture. Whilst analysing this phenomenon, I investigated the role of information asymmetry in maximizing/minimizing benefits/costs between WA and water users (farmers). I also investigate how does the magnitude and distribution of the surplus vary for society considering different economic characteristic and simulate how the introduced model would perform in some empirical conditions. While designing different scenarios and options, first attention is given to the theoretical context; then empirical examples are presented to test the hypothesis derived from theoretical models as a way of assessing the potential impact of the pricing instrument.

Each specific objective is addressed in a particular chapter developing a specific mechanism to match the respective objective. In any designed model, a principal agent relationship is analysed. The analysis helps to identify the range of outcomes that may emerge and might help to guide decisions on whether to further investigate incentive pricing mechanisms under asymmetric information and transaction costs on different cases. The study insights can contribute in identifying cases in which traditional flat rate water tariffs already exists, and new policy intervention might be needed and applicable to allocate irrigation water resource and guaranteeing cost recovery.

1.4 Overview

The work carried out is organized in eight chapters.

Chapter 2 provides an overview of economic and environmental relevance of water resource in agriculture. The chapter starts with a general introduction followed by description of instruments for the management of water resource for irrigated agriculture. In addition it provides the analysis of water prices for irrigated agriculture with a description of WFD principles and obstacles facing water agencies when designing and implementing policies. The chapter ends with the illustration of some lessons learned.

Chapter 3 describes a theoretical interpretation of WAs pricing strategies for irrigated agriculture in the absence of water metering under adverse selection. The modelling approach considers a reference case flat rate model that often is described as an *inefficient* solution for irrigation management. Its inefficiency is due to high water supply costs and low water conservation incentives. At least some of inefficiencies might be translated as a cost for the WAs because farmers are unrestricted in the amount of water use and, allow them using resource as much they can, their payment from the used resource are not in proportion with the amount consumed. With respect to the flat rate case, I develop a principal agent model relying on different information bases. First, the model is built under full information, considered as a benchmark; than the model is extended with cases under hidden information. I analyse the case of providing discriminatory water pricing scheme for water uses, referred to their water use function and generated costs to WA.

With regard to incentive tariffs, a stepwise model is build up with a set of examples. The decision variables of the model are water tariffs and farm's share of irrigated area. Outputs of the model include maximization of aggregated benefit, combining farmers benefit and WAs benefit. In this setting, aggregated benefit for different modelling conditions can be computed. The model considers heterogeneous farmers and identifies farms choice in response to a menu of contracts that reveals their types.

The structure of the chapter starts with objective setting, followed by the problem identification and presentation of the flat rate model. The chapter also describes incentive pricing considering several hypothesis under different information bases. Additionally, it is illustrated the effect of adding a participation constraint in the model. This is further extended by providing a summary of two pricing instruments (flat rate and incentive tariffs) and discussing its potential application. The chapter ends with some conclusions.

Chapter 4, describes a model based on menu of contracts with the purpose of providing an efficient water pricing scheme for irrigated agriculture. The developed approach is based on a principal agent model and still relies on an adverse selection perspective. This chapter differs from the previous one because assumes four farm types in a principal agent relationship and focus on an empirical application. In addition, the purpose of this chapter is to examine the impact of asymmetric information on the regulator's decision problem of assigning a share of irrigated area and water tariffs. I examine its implication and compare with the flat rate water tariffs. The provided empirical example considers different level of water costs. In addition, the empirical illustration provides some insights in terms of policy parameters (payments and share of irrigated area) profits, net profits, and social net benefit.

The structure of the chapter starts with the objective and then introduces materials and methods followed by a case study selected in a region of Albania. The chapter continues with results identified with some empirical simulations. The chapter ends with some discussion and conclusions.

Chapter 5, consist on the analysis of an optimal water pricing strategy through a monitoring scheme that aims at investigating the water users' exposure on overusing the water resource. The modelling approach is based on a principal agent theory to guarantee a sustainable water use for irrigated agriculture. In addition the model attempts to incentivize farmers to use the water resource based in the agreed contract instead of taking costly action.

Under this reasoning, I analyse a case leading to monitoring strategy to control farms behaviour toward the water resource and then discuss and compare results with a flat rate option. I tend to discuss how monitoring strategy and probability of detecting compliant/noncompliant farmer affect the levels of social benefits, farms tariff and irrigated share of farmland. In addition I investigate how monitoring activities serve to guarantee and contribute for a sustainable water demand management.

The chapter starts by defining the objective, and then describes materials and methods followed by subsections containing the background literature, the flat rate model, incentive strategies under full information and moral hazard assumption; it continues with an evaluation of two pricing strategies (flat rate and incentive tariffs). In addition, the chapter involves an empirical example comprising a case study and the descriptions of results. The chapter ends with some discussion and conclusions.

Chapter 6, describes a pricing scheme with the aim of developing a mechanism design that involves a monitoring strategy with the purpose of detecting farms action. In this chapter, differently from the previous one, monitoring costs are a function of monitoring efforts. The modelling aims at identifying under what level of monitoring frequency, monitoring strategy is efficient.

The structure of the chapter begins with the description of the objective, followed by the theoretical interpretation of the developed model. Then the chapter presents an empirical example for testing the model's hypothesis. The chapter ends with some discussion and conclusions.

Chapter 7, discusses and compare findings of the previous chapters, in relation to the contribution to the literature and implications for future impact analysis. Additionally this chapter draws some policy implications. The chapter ends with model limitations and future research.

Chapter 8, conclude the thesis with some main conclusions.

Chapter 2

2. The Economic and Environmental Relevance of Water Resources in Agriculture

2.1 General introduction

Most of worldwide water use goes for agriculture, accounting for about 70% of freshwater withdrawals and over 40% of OECD countries' total water withdrawals (Garrideo and Calatrava, 2010). The water resource of irrigation is withdrawn from rivers, reservoirs and lakes, and groundwater and usually supplied for irrigation through open canals or pressurized pipes.

Climate change and population growth are considered the main factors causing tensions and competition for water resources. In addition, the increase of food demand is causing a huge impact on the scarcity of water for irrigated agriculture. In recent years, in several countries, statistical evidences show a decline in the quantity and quality of water resources, questioning for future availability (Hanjra and Qureshi, 2010; Viaggi et al., 2010; Zoumides et al., 2009; Vasileiour et al., 2014). In this framework, Mediterranean countries debated on their irrigated agriculture because of its high water consumption levels and its apparent inefficiency (Sagardoy and Varela-Ortega, 2010; Gomez-Limon and Berbel, 2000). These pressures led many countries to (re)think their water policies in order to improve water use efficiency (Zoumides et al., 2009; Vasileiou et al., 2014; FAO, 2004; Fragoso and Marques, 2015; Lika et al., 2016).

In this respect, in Europe, increasing water scarcity and climate variability, brought about the introduction of additional policies aiming at increasing water use efficiency and at achieving sustainable uses of the resource (Barouchas et al., 2016, Aidam, 2015).

The management of water resources in agriculture concerns the responsibility of WAs and users to guarantee that water resources are allocated efficiently and equitably and used to achieve socially, environmentally and economically beneficial outcomes (FAO, 2004; Garrido and Calatrava, 2010).

Regardless of the reason for reforming water policies, knowledge of the value of water is essential for efficient management and allocation of water and when designing policies, the value of water is also essential to compare impacts of water reform within and across sectors of the economy (Qureshi et al., 2010).

In the following I discuss the management of water resource in agriculture, then I focus to the pricing policies potentially applied for irrigated agriculture. In addition, I discuss the WFD principles. Furthermore it is analyzed the agency problem with regard to water pricing for agriculture. The chapter ends with some lessons learned.

2.2 The management of water resource in agriculture

The disparity between demand for water and water availability causes water shortage in many countries of the world (Sun et al., 2018). The water scarcity varies with its existence, the way of strategy development for its management. The management of irrigation water resources is a prior strategy to mitigate future water scarcity problems (Franco-Crespo and Sumpsi, 2017). The management of water resources has received increasing attention by experts and policy makers since the Dublin conference in 1992 which supported the application of instruments for the management of the demand for water, pricing mechanisms and regulatory measures (Dinar et al., 2015; Berbel et al., 2017).

The management of water resource seeks a holistic approach that distinguishes the complex relationships among all factors influencing the water demand. It requires involvement of supportive policies and comprehensive legislations with a coherent set of incentives and regulatory measurements to support these policies (Thivet and Fernandez, 2012).

In the past the management of water resources has been put in place in most areas to guarantee water availability for basic needs, sanitation and the production of food. The management of water resources were not based on the formal law but on traditional practices (FAO, 2004). The intensification of agricultural production lead to development of more coherent water management practices. Worldwide countries promoted the government involvement in irrigation management now are shifting to adopting of new strategies by involving farmers as a part of development of management and operation planes and leaving governments to focus on the management of water on the main system. In some regions the government distribution agency manage all the irrigation system down to tertiary canals. In other countries, the water management by governments is up to secondary canals and living the other part to be managed by users and in some other countries farmers may be engaged for the management of entire irrigation system.

A variety of water management systems exist but I highlight three basic types of irrigation management: First, water management by public sector such as an public irrigation department; second, water management by private entities a private corporation selling water from tube or wells which are more in the bases of trade rather than on the authoritative decision; third management via WUA, where the grope of irrigation users who share the common interest on the management of their irrigation resource (Groenfeldt and Sun, 1997), thought WUA not always maintain entire irrigation project, some duties belong to governments (i.e. building irrigation networks, reservoirs and maintenance of primary canals). In addition in some countries are applied also water markets as a way of managing the water resource.

Moreover, the management of irrigation water is sorted out through supply and demand. The management of water resource through supply consist in a structural allocation, leak detection and control systems in distribution network. This approach targets water users, instead of water suppliers, to achieve more sustainable allocation. Demand management approach consist of non-structural measures: economic and legal incentives to influence the behavior of water users and creation of the institutional and policy environment that enables this approach (Savenije and van der Zang, 2002).

The management of water resource through demand involves many instruments. In this regard I attempt to synthesize the indicators described by Savenije and van der Zaag (2002) and Kampragou et al. (2010). In general demand management of water resource is based in five principles:

- Implement water conservation practices (i.e. laws and criteria)

- Promote water conservation (i.e. provide positive incentives for rational water use taxes or voluntary agreements)
- Invest on water conservation (i.e. develop programs for preventing losses in irrigation networks, impose water metering, the use of quotas this mechanism is found to be preferred to a purely economic regulation for managing scarcity because they are more equitable, transparent and more efficient in meeting demand with supply)
- Application of economic instruments (i.e. economic incentives as water pricing, subsidies, grants, price differentiation; or other economic criteria penalties, legal enforcement incentives)
- Development of education programs or capacity building (i.e. setting examples, information campaigns, access to informant and data)

According to above instruments water pricing mechanism is viewed as one instrument to improve the economic efficiency of water resource. In this respect in the following section I attempt to assess the role of the economic instrument water pricing in relation with demand management for irrigated agriculture.

2.3 The issue of water pricing in agriculture

The management of water resource via water pricing has been considered as one of options for achieving WFD objectives with the purpose to ensure sustainable use of water resources (Gomez-Limon and Riesgo 2012; Toan, 2016) and to improve the efficiency of water uses in agriculture (Molle et al., 2008; Frija et al., 2011; Speelman et al., 2009; Giannoccaro et al., 2010; Shen and Reddy, 2016).

Many scholars that dealt with the issue of irrigation water pricing believe that the management of water demand via pricing is impractical (Molle, 2009). Some scholar argues that maintaining low water charges for irrigation send wrong signals to water users, who are not enough incentivized to cultivate water-efficient crops and/or to improve their irrigation technologies. Additionally, water pricing would not incentivize efficient water uses, unless prices are directly linked to water use (FAO, 2004). This is becoming a central issue for the WA in designing and plaining the use of the water resource (Masseroni et al., 2017). In this regard some authors highlight that the management of water demand via pricing should be further investigated and should integrate the social value of the water resource (FAO, 2004, Tiwari and Dinar, 1997).

Pricing is deemed as a potential and desirable tool to arbitrate water allocation between sectors and to promote desirable environment objectives. Water pricing involves any charges that farmers have to pay for using water (Garrido and Calatrava, 2010; Tiwari and Dinar, 2000). In the most general sense, water pricing refers to monetizing the abstraction, the use and the pollution of water. Following this broad definition, pricing is not a water allocation mechanism in itself, but is a supporting policy instrument to control water use (or pollution) and (re-)finance water use-related costs (ARCADIS, 2012).

Nowadays, a variety of methods of water pricing and water allocations schemes exists. This wide range of water pricing schemes adopted by WAs worldwide depends on the infrastructural and socio-economic conditions that characterize the irrigation network served by the WA as well as on the broader institutional and administrative context.

In the following I cluster existent water pricing approaches in few main categories:

Table 2.1. Water pricing categories

1. Area-Based Charges	(a) A fixed rate per hectare of farm, where the charge is not related to the area irrigated, the crop grown or the volume of water received. It is usually part of a "two-part" tariff designed to cover the fixed costs of the service. Different tariffs may be used for gravity and pumped supplies. (b) A fixed rate per hectare irrigated. The charge is not related to farm size, type of crop grown or actual volume of water received (except that a larger irrigated area implies a greater volume of irrigation water).
2. Crop-Based Charges	A variable rate per irrigated hectare of crop, i.e. different charges for different crops, where the charge is not related to the actual volume of water received, although the type of crop and area irrigated serve as proxies for the volume of water received.
3. Volumetric Charges	(a) A fixed rate per unit water received, where the charge is related directly to, and proportional to, the volume of water received. (b) A variable rate per unit of water received, where the service charge is related directly to the quantity of water received, but not proportionately (e.g. a certain amount of water per hectare may be provided at a low unit cost, a further defined quantity at a higher unit cost, and additional water above this further quantity at a very high unit cost). This method is referred to as a rising block tariff.
4. Tradable water rights	The entitlements of users in an irrigation project, or more widely, other users, are specified in accordance with the available water supply. Rights holders are allowed to buy or sell rights in accordance with specified rules designed primarily to protect the rights of third parties. Sales require authorization by a licensing authority (as in the Murray Darling Basin Authority, Australia, and most western states in the United States of America), or may require court approval (e.g. Colorado, the United States of America) without reference to any specified authority.

Note: The source of this table is FAO 2004, 28 Report

- *Non volumetric water pricing*

  Most of irrigation water district use non volumetric water pricing strategies: input pricing, output pricing, area pricing, flat rates and betterment levy (Tsur et al, 2010; FAO 2004). Output pricing scheme implies water charges based in each unit of output produced by the user (Tsur et al., 2010). If the output is observable this pricing scheme avoid the accuracy of transaction costs (Tsur et al., 2010). Input pricing scheme involves water charges based on water consumption, taxes on water-related inputs for example per unite charge for each unite of fertilizer purchase (Tsur et al., 2010). In case of area pricing method users are charged for water use for irrigated area, often depending on crop choice, extend of crop irrigated, irrigation method and season. Flat rate water tariffs usually are applied based on area irrigated (Lika et al., 2016). In addition betterment levy pricing method is based on the implicit value of irrigation water by charging water fees per unite area, bases on increased in land values (Tsur et al, 2010; Tsur and Dinar, 1997).

- *Mixed tariffs*

  These charges combine area or crop based flat-rate with a volumetric element and are also called two-tiered or two-part tariffs (ENTEC, 2010). Countries like Austria, Czech Republic, Finland Germany, Ireland, Poland and Spain are using mixed tariffs to recover supply costs for irrigation water in agriculture.
- *Volumetric water pricing*

  This water pricing method is base in volume water consumed. Volumetric water pricing requires information on volume used and seeks that WAs to establish prices, monitor water usage and collection of fees (FAO, 2004; Tsur et al, 2010). Volumetric charges implies also linear volumetric charges, usually applied in Cyprus and Luxembourg, and volumetric block tariffs applied in Belgium (ARCADIS, 2013). Volumetric methods supplying water to individual farmers are not feasible always in practice because of the high costs of implementation mainly for a high number of fragmented farms, instalment of volumetric measures are often prohibitively expensive because of complexity of installing and large number of measures device and especially in large areas (FAO, 2004; Molle and Berkoff, 2007; Molle, 2009)
- *Water Markets*

  It has long been recognized that markets provide a means to allocate water according to its opportunity cost, and should result in an efficient and conservation tool (Tsur and Dinar, 1997; Johansson et al., 2002; Tsur et al, 2010). Water markets consist in a more flexible water allocation mechanism than administrative means. The allocation of water traditionally belongs to WAs and are underutilized in many areas where they are appropriate. However, the allocation of water resource through market mechanism has been questioned in developing countries. This strategy requires development of institutions and infrastructure for operation (Johensson et al., 2002). Its application is very limited because involves substantial externalities, recharge considerations, lack of information, high cost of investment and decline average costs of delivery (Tsur et al, 2010). The application is partially applied in Spain and United Kingdom and they are the only European Countries partially apply this mechanism. In some other countries, like Romania, the trading of water rights is explicitly prohibited. In addition, OECD (2010) confirms that the use of water markets and trading of water entitlements to allocate water is practiced only in a very limited number of OECD countries (i.e. Australia) (ARCADIS, 2012).

In spite of this instruments discussed by scholar, in practice, most of WAs recover supply costs by flat rate pricing schemes whatever is the availability of water resources (INEA, 2011; Bazzani et al., 2004; Molle et al., 2008; Lika et al., 2016). Flat rate instrument is relatively easy to be designed and to be implemented, with relatively low transaction costs. This scheme appears to be not economically efficient, since water charges are not depending on the amount of water used. Under this pricing scheme water uses pay evenly, whenever they are or are not irrigating (Molle and Berkoff, 2007; ARCADIS, 2012). Volumetric pricing is applied in those rare circumstances where water uses are metered or, at least, monitored but is not always implementable as it implicitly requires the measurement of the water withdrawals by farmers. Appendix[1] 2.1 provides a comprehensive list of water pricing schemes currently applied in different EU regions.

With respect to the past literature, below I provide a review of some recent studies provided by scholars in the way of assessing the effect of pricing policies to a particular sector.

Molle et al. (2008) describes roles of water pricing and its limitations surrounding efficiency of water pricing mechanisms. I looked at the main practical obstacles related to pricing mechanisms: a) increasing prices generally has no impact on irrigation efficiency unless the water resource prices are set on the bases of the volume used; b) in cases when water prices are set based in volume used, prices are invariably too low to induce a charge in behavior. This is right because pressurized systems are associated with high value crops that mean water costs are negligible in the crop budged, efficiency is already high and costs of achieving higher efficiency would normally offset any gain from a lower water charge. In addition the author indicate that water payments exceed operation and maintenance (O&M) only when are included additional payments in form of taxes, which usually under management of public authorities users are unlikely to accept paying more than the cost of supply (anything beyond this is considered as a tax and is rejected), in case when the management of water resource belongs to farmers, they never self-inflict prices higher than O&M costs. In addition, the author argue that pricing policies are highly related with political economy and its adaptation in the region is limited by political implications.

Aidam (2015) uses a mathematical programming approach aiming at analyzing the impact of water pricing policy on the demand for water resources by farmers. The author's empirical simulation show that water pricing is negatively correlated with water demand for irrigation, mainly for significant high prices. In this line, Omid et al. (2016) introduce a nonlinear modelling in order to estimate farmer's willingness to pay (WTP). The WTP was estimated though a probabilistic optimization method. Their empirical result show that for low water cost, water use is not responsive to pricing. The authors conclude that rationing increase water pricing and water use declines. The decline of water use is associated with decrease of the cost of water supply. In tem of policy implication Adam (2015) highlight the importance of further investigation pricing policies but not only by scholars to reform the management of the water resource as a mean of improving water use efficiency. In addition, the design of pricing policy that would incentives farmers toward less water consumption would be a good policy incentive and advisably to be combined with other non-pricing instruments like water harvesting and other water saving technologies in order to achieve a meaningful result.

1 The appendix 2.1 refers to ARCADIC 2013 water report, more details can be found in the report.

Frogos and Marques (2015) design a Positive Mathematical Programming (PMP) as an alternative, Econometric Mathematical Programming (EMP) based in the estimation of optimality condition with the purpose of assessing the economic impact of water pricing in the context of public irrigation scheme. The policy was designed to assess its impact on water demand, irrigated land rate, farm profit, cost recovery and total welfare. In addition authors compare two pricing policies volumetric tariffs with a block tariffs. They found that bloc tariffs achieve the most efficient water allocation, when farmers, water average cost is below 50 Euro/1000m^3. Authors conclude that the two part tariff (i.e. two part tariff implies fixed and volumetric part) perform better then volumetric pricing. Authors argue that EMP perform better in term of efficiency than PMP capturing farmer response in terms of crop substitution to water availability and pricing policy change. In addition, the authors highlight the need of implementing a more efficient water pricing polices above all to manage the risk arising specially by climate change.

Franco-Crespo and Sumpsi (2017) illustrate a Positive Mathematical Programming (PMP) with the purpose of analyzing the economic impact of pricing policies on agro-food farms. The authors describe and assess three pricing policies: flat rates, water blokes and volumetric pricing. The authors' results indicate that flat rates have higher cost/revenue ration than other simulated pricing policies. The application of a block tariff represents a greater effect on incomes of farmers. Moreover, a volumetric rate, depending on the value of the water allocated can influence the reduction of water consumption and thus reduce the negative effects on farmers' incomes.

The most efficient method turned to be volumetric pricing with low impact on the proceeds of farmer and having the capacity of reducing the water consumption. Nevertheless the authors conclude that volumetric water pricing seeks additional costs for the implementation measurement adaptations. In addition from the survey authors found that for a hypothetical increase of the price of irrigation farmers respond by reducing the cultivated area or even deciding to abandon the agricultural area or shifting toward a rainfed crop cultivation. Moreover, in this line, Vasileiou et al. (2014) assess the impact of different policy measures in the irrigation performance. The alternative intervention measures implies the abstraction quota restrictions and volumetric pricing with the purpose of increasing the water use efficiency and ensuring rational water use. In order to assess the impact of this instruments a Linear Programing (LP) was used. The authors found that an increase of the water pricing beyond £1.00 m3 drive farmers do decrease the demand for irrigation and eventually decreasing the WAs revenue from fee collections. In addition they highlight the regulation via quotas, where there are pressures systems, in order to achieve the most efficient level of water use. In this regard, pricing strategies can be combined with many other instruments like quotas (i.e. setting an upper limit to the amount of water that may be used) or other economic incentives (i.e. subsidies, penalties, etc.)

Most of the analyzed literature focuses on analyzing farmers' responsiveness to water pricing. The majority of scholars analyzed and developed different pricing strategies to incentivize rational water uses under different conditions. The conclusion of most authors is that beneficiaries should pay the full ongoing costs of system operation, maintenance, replacement and upgrading of facilities. Such payments should be clearly designated for users by the operating agency, and accounting procedures should be transparent and encourage efficiency in the operating agency.

With the focus to water pricing, a deep and comprehensive analysis of the management of water resource for irrigated agriculture is proved in the books of Tsur et al. (2010), Buarnaris et al. (2015) and Dinar et al. (2015).

2.3.1 Water Framework Directive

The EU WFD intended to bring a new regulation for the management of water resources (Teodosiu et al., 2003; Viaggi et al., 2010; Voulvoulis et al., 2017). The WFD goal was to create a framework to regulate the use of European water bodies. The Directive also required the coordination of different EU legislation and established a detailed schedule for action, with the year 2015 set as the target year to reach a good status for all European water bodies (European Commission, 2012a; Erik, 2015; Giannakis et al., 2016; Voulvoulis et al., 2017).

Despite the fact that the target year already passed through, EU Member States are still struggling to redesign their management, including water-pricing policies in a way that is consistent with the WFD principles. Specifically, the WFD introduced few fundamental principles to design water pricing:

- Full Cost Recovery (FCR) shall include the recovery of the costs of water services including environmental and resource costs having regarded to the economic analysis conducted according to Annex III[2]
- Incentive pricing principle (IPP) indicate that water-pricing policies provide adequate incentives for users to use water resources efficiently, and thereby contribute to the environmental objectives of this Directive,
- The Polluter Pays Principle (PPP) that looks at the adequacy of contributions to compensate for the cost of environmental damage generated by users;

These principles emphasize the twofold purpose of pricing for water use, namely financial and economic. From a financial viewpoint, payments enable the WA to recover all or part of the capital and current costs. From an economic viewpoint, payments allow WA to conserve water and increase the efficiency of water use. Toan, (2016) aim at providing an international review of water pricing policies by focusing on the alignment of costs with prices. The study promote a policy change with a focus to a more sustainable irrigation management. The author highlights the importance of development and imposition of acceptable price regime in order to answer to the question how do we get farmers to pay the costs associated with water and water delivery. In addition the author highlights the importance of identification of what farmers must pay for with

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2 The economic analysis shall contain enough information in sufficient detail (taking account of the costs associated with collection of the relevant data) in order to:

(a) make the relevant calculations necessary for taking into account under Article 9 the principle of recovery of the costs of water services, taking account of long term forecasts of supply and demand for water in the river basin district and, where necessary: estimates of the volume, prices and costs associated with water services, and estimates of relevant investment including forecasts of such investments;

(b) make judgements about the most cost-effective combination of measures in respect of water uses to be included in the programme of measures under Article 11 based on estimates of the potential costs of such measures (European Commission, 2000; European Commission, 2010) regards to various costs components of irrigation water (i.e., O&M costs, capital costs, resource cost, and environmental costs), and stress the fat that factors that shape these attitudes, are largely unexplored.

The core elements considered when designing pricing policies are recovery of full costs of water services and creation of incentive for efficient water use. Yet this objective are not meet in especially in developing countries. The main factors affecting to not reach this objective are: the provision of large subsidies to water users (i.e. subsidies often are applied in cases when the irrigation water is under public system); water prices for irrigation are generally underestimated in a way of not covering the cost of delivery; capital investment are not included on the irrigation payment; most of water agencies do not set water tariffs on the bases of individual water use; lack of incentive mechanisms for rational water use.

The main assumption underlying the WA's capacity to accomplish the above policy objectives by way of prices is related with his direct or indirect knowledge of the quantity of water used by individual sectors or agents (Galioto et al., 2013)

In addition, it is normally accepted that water pricing should be linked to the actual use/abstraction or that there is a contribution from all users in relation to their consumption (or pollution). This usually is referred to as the PPP, but its application in practice is often subject to debate (ARCADIS, 2012). The adaptation of the PPP might be associated with an increase of prices from the necessity to recover environmental costs caused by agricultural practices (i.e. nutrient leaching). This leads WAs to set water prices in a higher level. The increase of water prices through the application of PPP might prevent water users from abusing with the resource. The application of the IPP makes it possible to solve this discrepancy, and also contributes to reducing pressures on water resources. Thus, the application of IPP mechanisms would allow WAs to comply with the WFD principles, but its applicability relies on the assumption that the WA is able to implement and to observe users compliance. In addition, the effectiveness of incentive pricing in conditioning both water uses and distribution of costs among users, depends on farms' readiness to accept water tariffs and comply with proposed rules.

In this regard, many EU countries are providing a particular attention in developing incentive pricing strategies that would guarantee an efficiency of water use and moving away from flat rates (Franco-Crespo and Sumpsi, 2017). For example, Dono et al. (2010) investigate the potential impact on water use and the economic effect of increasing water prices in a Mediterranean agriculture with a focus in southern Italy. The authors compared a volumetric water pricing scheme with a flat rate prices. They argue that the adoption of flat rates was favored only if adequately estimated by the Water Users Association (WUA) as is easier to recover the costs of the service.

2.3.2 Agency problem and implications of information asymmetries

The effectiveness of a pricing policy adopted by local WAs to allocate costs among users and to dis-incentivize water misuses, in accordance with the WFD principles, changes considerably depending on several factors. The development and implementation of efficient policies to manage the demand for irrigation water by WAs is a challenge due to conceptual and practical constraint faced (ARCADIS, 2012).

The absence of water metering is the main constraint. Water for irrigation is mostly delivered through surface irrigation networks. Under such condition, metering individual water use is costly and difficult, since it requires a hydraulic device to measure the flow at the head of each farm. Moreover, costs associated with monitoring water flows are prohibitive unless water is pressurized and meters can be installed (Molle, 2009). This condition hinders the ability to monitor the volumes actually used and to implement volumetric pricing as a way of allocating costs and ensuring efficient water use (Viaggi et al., 2010; Johansson et al., 2002; Smith and Tsur, 1997; Galioto et al., 2013, 2015; Lika et al., 2013). In addition, lack of water metering inhibit the WA to design water pricing strategies that suit best for farmers and regulators due to high level of transaction costs.

Transaction costs implies costs of administration, implementation, enforcement and monitoring. The level of transaction costs is conditioned by the presence of information asymmetries between WAs and users. Transaction costs related with administration and implementation involve the costs the WA face to administer, manage or establish tariffs and collect to water users in a given irrigation sector.

Information asymmetries usually makes impossible by the WA to fully recognize the manner in which individual users exploit water resources (Galioto et al., 2013). Under such condition, rational and opportunistic individuals may behave on their own interests to the detriment of the community of users or even the society (Johansson et al., 2002).

Implications of asymmetric information can be overcome if WAs possess technologies and tools that make available the necessary information about farmers' behavior. On the other hand, the implementation of technologies is conditioned by the enforcement capacity of the regulator (transaction costs, rents, monitoring and sanctioning).

The design of policy with farmers is often characterized by two types of incentive problems of asymmetric information: adverse selection and moral hazard (Hart and Latacz-Lohmann, 2005). Adverse selection (hidden information) occurs when the water authority (WA) may know the existing farm types, but is unable to observe each farm type belong to whom (Lika et al., 2016). Moral hazard (hidden action) occurs if the regulator cannot monitor compliance perfectly, farmer has an incentive to cheat if the expected pay-offs to cheating is greater than the pay-offs to the alternatives (Hart and Latacz-Lohmann, 2005; Ozanne and white, 2008).

For the reason that the farms behavior is not observable, some farmers may behave opportunistically being noncompliant with the rules agreed with the WA. The information advantage that farmers possess might be used to attain higher profits to the detriment of other farmers (Vedel et al., 2006). If the WA do not monitor farms' action the probability that farmers will act dishonestly would increase (Rothkopf and Pibernik, 2016). This is a common problem in the sphere of irrigated agriculture, that's why the EU highlights the importance of finding the appropriate tools and incentive mechanisms to reduce the negative effects of information asymmetries in irrigated agriculture (European Commission, 2015).

When farmers' actions are observable, the WA can set pricing policies based on individual water uses. When the individual water use is not observable, it is possible to price water indirectly through other observable variables (Smith and Tsur, 1997).

There is a broad body of literature that address the issue of asymmetric information through the application of principal-agent theory in agriculture (Moxey and White, 1998; Moxey et al., 1999; White, 2002; Hart and Latacz-Lohmann, 2005; Choe and Fraser, 1988; Ozanne et al., 2001; Millock et al., 2012; Fraser. 2002, 2013); Lika et al. 2017. However, few scholars studied irrigation water pricing under asymmetric informant for surface irrigation network. Literature focusing on this issue and serving as a point of departure regarding this thesis are: Smith and Tsur (1997), Gallerani et al. (2005), Viaggi et al. (2010), Arguedas and van Soest (2011), Galioto et al. (2013, 2015) and Lika et al. (2016).

Smith and Tsur (1997) initially addressed the issue of water pricing under asymmetric information. They introduce the mechanism design to overcome the problem of adverse selection and moral hazard in the absence of water metering. They applied a direct revelation mechanism in order to soften the level of information asymmetry between farmers and the WA. They argue that the presence of asymmetric information hinders the allocation of resource and regulation is needed as a form of setting output/input price combination or imposition of a tax on output. The authors argue that in the absence of transaction costs first best solution is attainable. With the presence of transaction costs, a second bests solution is achieved. In addition, the authors provide a numerical example where they argue that under certain level of transaction costs, the introduced mechanism is not effective and beyond a certain level of transaction costs is better to not introduce policy regulation.

Furthermore, they highlight that the literature of water management under asymmetric information conditions has received little attention and emphasize the importance of analyzing the effects of asymmetric information in a policy design issue and its effect on limiting the market mechanism in allocating water resources.

Dridi and Khanna (2005) introduced a model while studying the efficiency of water trading under asymmetric information and different irrigation regime. They developed a mechanism for water pricing and examined its implication for adoption of modern irrigation technologies under different information circumstances. Their model show that hidden information significantly reduce the adoption of modern irrigation technology and lead to more retirement of poor quality lands than under full informant. Authors demonstrate that water trading even under asymmetric information can improve the allocation of water resource.

Gallerani et al. (2005) introduce a linear programming model to address the issue of water pricing for irrigated agriculture under asymmetric information. The authors use a menu of contracts as a mean of linking payment and share of irrigated area in function of water use. Their objective was to design optimal water pricing scheme under asymmetric information and transaction costs (i.e. transaction cost in their study arise from the money transfer). Authors compare the new scheme with traditional flat rate and they found that flat rate is an unsuitable tool for guaranteeing social feasibility of irrigation water and leading to an optimal solution based on the abandonment of irrigation. They found that improvement of social benefit from irrigation water might be achievable even under the existence of asymmetry of information and transaction costs. They argue that transaction costs have almost no effect when the full cost of water is very low. In addition, the actual social cost of water plays a crucial role not only for designing payment levels, but also in influencing the selection of the correct policy instrument.

The authors argue that the applicability of contract theory is highly linked with the characteristic of farm types. The authors emphasize the need to investigate of what influences farmers to move on the production function as a function of price incentives and how they will behave under a given policy. In addition, the authors emphasize the importance of addressing this concern and how the contracts should be designed in order to achieve better insights to support WAs for decision-making policies.

Viaggi et al. (2010) provide a comparison between a flat rate tariff and a menu of contracts. They note a higher variability (hence less political feasibility) in the menu of contracts option, where payment differentiation associated to the differentiation of the share of irrigable land is the key component determining the self-selection on the part of farmers. In some cases, using real data farmers pool together in such a way that differentiation among farmers become inapplicable. Additionally, the effect of price on optimal contract design, amplified by the need to provide discriminating incentives in the contract solution adds to other considerations in pushing for a flat rate as the menu of contracts appears too sensitive to product price scenarios and would likely fail to discriminate correctly between farm types if the actual prices were different from the expectations of the public regulator.

In addition authors highlight the importance of assessment and improvement of the methodologies toward incentive-oriented pricing mechanisms would be of interest of policy-makers considering situations of unmetered irrigation water use.

Arguedas and van Soest (2011) provide a theoretical analysis of the optimal conservation contracts under asymmetric information conditions and trying to assess the role of fixed costs on the policy design and discuss the prominence of the use of menu of contract for the conservation services. In addition, the authors highlight the importance of assessment of factors that affect the policy shifting from fist best to the second best solution and distinguish how added factor (i.e. fixed cost) impact the solution of the mechanism design and affect the regulators decision to collect the necessary information until push him to select other costly-effective mechanism (i.e. like conservation action). However, the authors provide evidences when incentive-compactible conservation contracts are worthy to be assessed and implemented.

Galioto et al. (2013) analyzed pricing policies in managing water resources in agriculture when the water is unmetered, aimed at verifying whether existing area-based tariff strategies are efficient economic instruments for water policy and to what extent alternative design in the direction of irrigated area-based instruments can help in better complying with European water policy principles. The water pricing model in this study was two tariff regime. The first one, tariff imposed on the entire farmland area (no mater share of irrigated area). The second one based in per hectare tariff proportional to the irrigated farmland. They found that the existing tariff policies, presently based on an area-based flat rate system is justified if transaction costs, due to the need to monitor at least irrigated areas under no metering conditions are lower than the difference of benefit between two scenarios. From this perspective, the WA should adjust the tariffs for irrigation water uses according to the type of priority (funding and/or environmental protection) and in compliance with the criterion of cost sharing (equity).

Recently, Lika et al. (2016) developed a water pricing scheme under asymmetric information when water is distributed though surface irrigation networks. The authors introduce a social welfare maximization water-pricing scheme using empirical information from an Albanian region. As a mean of designing an efficient water-pricing scheme for irrigated agriculture, a nonlinear model was used based in menu of contracts and compared with flat rates which is the common pricing method applied in the region. The authors found that a second best solution might yield an improvement of social welfare compared with traditional flat rate water pricing. In addition, appropriate contract-type pricing schemes have a significant role in providing incentives to farmers to make irrigation choice to the social optimum.

Furthermore, the authors highlight the presence of information asymmetries and the need for exploring and reforming water pricing policies in such regions that have recently witnessed stronger institutional change and major regulatory instability. Additionally the authors attempt to prepare the background for further application and development of water pricing policies in other areas with similar characteristics.

Galioto et al. (2015) analyzed incentive water pricing under adverse selection and moral hazard and comparing the discriminatory pricing strategies with a per area based tariff with and alternative discriminatory pricing strategy that faces both the issue of adverse selection and moral hazard. The authors conclude that the viability of monitoring strategy depends from the water regulator's strategy to monitor farmers and its ability to identify monitoring costs. In this respects the authors emphasize the need for a further investigation of less costly strategies for identifying positive signals, which boost farmers toward compliance.

Lika et al. 2017 analyze a case of incentive water pricing for irrigated agriculture under the presence of moral hazard and transaction costs. The authors discuss a case when the WA aimed at applying incentive water pricing when the irrigation water is served through surface irrigation networks. The paper analyses a case when, farmers may own private information on water use which is unknown to the WA and they may take opportunistic actions totally or partially undetected by the WA (i.e. irrigation higher irrigated then declared ex ante). The design of incentive water pricing is with a purpose of sharing water supply costs among water users based on theirs water use function and dis-incentivizing farmers from water misuse, in contrast with the flat rate where farmers benefit from payments that are set equally among farmers.

All of these instruments differ in the identification of indirect signals, improving the quality of information flows which contribute to influence the level of compliance within the irrigation network. That is, for a given organizational arrangement of the irrigation network the level of compliance is favored by an increasing quality of information flows.

The above literature can be summarized by saying that in the absence of water metering it is hard to identify indirect incentives for conditioning both the way to share supply costs among users and the way to affect the allocation of water resources via pricing. However, the literature shows that the menu of contract with respect to the field of irrigated agriculture is little explored and further exploitation of such instruments might be considered as a mean of providing relevant insights and with a policy dimension.

2.4 Lessons learned

Over the years, water charges for irrigation has bend developed based on the needs of utilities and water users and on the basis of advances in technology. The past literature that compare the efficiency of water pricing across different water pricing methods and compare experiences among different countries includes Dinar and Subramanian (1997), Tsur and Dinar (1997), Dinar and Subramanian (1998), Johansson et al. (2002), Tsur et al. (2004), FAO et al. (2004), and Molle and Berkoff (2007). The main conclusion of this authors and others that provide a comparison of water pricing performance among countries is that there is no best practice that can be recommended to one county or region (Dinar, 2015).

The author's recommendations are that economic instruments, water pricing, can significantly affect to a policy framework by incentivizing users behavior and leading to efficient allocation of water resource and to the improvement of the amount of fee collection which in return being invested to guarantee to supply of the water resource for water users. In addition, water-pricing policies should not be used to incentivize rational water uses on its own but should be used together with other water saving policies in order to achieve appreciable impacts. This suggestion is also motivated by the fact that water pricing affect production costs and essentially farmers' competitiveness and, usually, water pricing levels cannot exceed socially acceptable threshold values.

As it turns out, despite the fact that many high-income countries are improving their water pricing policies by introducing pricing strategies in function of individual water use, yet the application of incentive strategies is fare from reaching WFD objective. In most circumstances transaction costs may be prohibitively high, preventing from adopting incentive tariffs and/or limiting its effectiveness. Thus, the level of transaction costs condition whether or not to adopt incentive tariffs, the ways incentive tariffs could be implemented, the relevant effectiveness in terms of impact on water uses as well as on the allocation of supply costs within the community of users.

However, further investigation must be made by considering other factors that influence pricing method. In this respect, the EU commission highlights the integration of water management through water pricing policies in combination with other non-pricing measures. Strategies of water demand management needs to find the right combination of pricing and non-pricing instruments to achieve efficient and sustainable use of water resources in agriculture (EEA, 2017; Tiwari and Dinar, 2003).

Chapter 3

3. Designing a Theoretical Principal Agent Model under Adverse Selection.

Paper under review[3]

3.1 Objective

The objective of this chapter is to provide a theoretical analysis of incentive water pricing for irrigated agriculture under the problem of adverse selection. The study also aims at identifying conditions affecting the efficiency of pricing strategy.

Theoretical analysis is carried out by using a principal agent model, this method is widely applied in the field of agriculture economics. In this respect the study deals with a case where the WA (principal) supply the water resource to a community of farmers (agents) and farmers in return pay water tariffs for irrigation. Firstly the study adopt a framework based on the flat rate model of water pricing which is mostly applied in the field of irrigated agriculture, especially when the irrigation water is unmetered. Secondly with the main focus I develop incentive pricing strategies as a mean of linking water tariffs with the amount of water use by farmers. To this end the study assesses the efficiencies/inefficiencies coming from the development of these pricing policies.

The paper is organised as follow, section 2 describes the problem surrounding the use of water resources in irrigated agriculture; section 3 introduces the flat rate model; section 4 deals with incentive tariffs of water pricing. This section analysis the model and illustrate the problem, starting from a simple case with full information and then extending it to include asymmetric information. The section involves 5 subsections: The first and second subsections consider the design of pricing strategy when the WA face the same water cost function of providing the water resource under different information conditions (full and lack of information); in the third and fourth subsections are analysed cases of different information conditions with different cost functions and in the fifth subsection is discussed the effect of an participation constraint in the model. Section 5 provides some synopsis of two pricing policies flat rate and incentive tariffs; section 6 is devoted to the discussion of the developed pricing policies. Finally, section 7 presents the main conclusions.

3.2 The Problem

Information asymmetries usually make impossible by the WA to fully recognize the manner in which individual users exploit water resources (Galioto et al., 2013). Under such condition, rational and opportunistic individuals may behave on their own interests to the

[3]A slightly modified version of this chapter is under review as an article as follows: Viaggi, D.; Galioto, F.; Lika, A. The design of pricing policies for the management of water resources in agriculture under adverse selection. *Journal of Water Resource and Economics*

detriment of the community of users or even the society (Johansson et al., 2002). This is a common problem in the sphere of irrigated agriculture, that's why the EU highlights the importance of finding the appropriate tools and incentive mechanisms to reduce the negative effects of information asymmetries in irrigated agriculture (European Commission, 2015).

A typical agency problem surrounding the use of water resources in agriculture arises when farmers withdraw water to irrigate from surface irrigation networks managed by a private or public regulator. Here, farmers own private information on water uses which is unknown to the water regulator. Due the impossibility to monitor directly water usage it is difficult for the water regulator to price water according to the amount effectively applied by the farmer, which depends, in turn, on farmer's characteristics.

In this reasoning the above problem is analysed by developing the method used by Viaggi et al. (2010), Galioto et al. (2013) and Lika el al. (2016); the conceived model is based on the textbook models illustrated in Bolton and Dewatripont (2005) and Laffont and Martimort (2002). In the following, I analyse the economic implications under two pricing instruments flat rates and incentive tariffs.

3.3 Flat rate model

In most cases, for a surface irrigation network the WA applies flat rates, especially when there is no limitation in the availability of the water resource and differences in water use cannot, or are too costly, to be assessed. This condition motivates the imposition of flat rates by WA even if the level of water use varies. With flat rates, farmers are charged equally whether they are or they are not irrigating (Molle and Berkoff, 2007) or if they are using more or less water. In such a way, during the irrigation season farmers take the decision on how much to irrigate and when, without being influenced by the price paid to the regulator for the supply of water, because tariffs play just the role to recover supply costs but have no role in terms of incentives to optimise the use of water. The regulator requests to the farmer to pay the agreed tariff in order to recover costs that he faces to supply water during the irrigation season. In this framework, farmers' decision on water use is independent from the cost faced by the water regulator to supply the service, while the supply cost depends on water use.

From now on, without loss of generality I will consider the share of irrigated area as the decision making variable by the farmer (determining water use and hence the supply cost for the regulator). Moreover, it is assumed farm size equals 1 for each farm type served by the water regulator and considered a per hectare profit which is function of the share of irrigated area. The assumption considers farmers to have a nonlinear profit function, while the WA faces linear water supply costs with respect to the irrigated share: $\pi_i'(x_i) > 0$, $\pi_i''(x_i) \leq 0$ and $c_i'(x_i) > 0$, $c_i''(x_i) = 0$, where i represents the farm type and x_i is the share of irrigated area with respect to the type i.

Under this condition, a rational farmer will choose to irrigate the share of irrigated area that will let him maximize profits, according to the following maximisation problem:

$$\max \mathrm{V}_i(x_i) = \pi_i(x_i) - t \tag{3.1}$$

The maximization problem is defined as the difference between farmers profit from the use of water $\pi_i(x_i)$, and the tariff paid by the farmer to the WA for the supply service t. By taking the First Order Condition (FCO) from equation (3.1) with respect to the irrigated farmland, x_i, it is obtained the optimal level of the share of irrigated area, which is determined when the marginal profit equals zero, being t fixed irrespectively of the amount of irrigated land:

$$\pi_i'(x_i) = 0 \tag{3.2}$$

Equation (3.2) indicates that the value of the flat rate tariff does not affect the farm choice about the share of irrigated land. On the other hand, the optimal share of irrigated land is different across farms, depending on farm's i profit function. Let's call this level x_i^{FR} where the superscript FR indicates flat rate, given by solving equation (3.2).

The objective function of the regulator can be seen in different ways. The one used here is assuming that the regulator aims to optimize the social benefit, S, given by:

$$S = \sum_{i=1}^{n} \delta_i[(\pi_i(x_i) - c_i(x_i) - vt] \tag{3.3}$$

Subject to:

$$\text{CR: } t \geq \frac{\sum_{i=1}^{n} \delta_i c_i(x_i^{FR}) + vt}{n} \qquad \forall i \in n \text{ and } \forall v \leq 1, \tag{3.4}$$

Where, $c_i(x_i^{FR})$ are the costs faced by the regulator to divert water for irrigation into the network to meet the demand; δ_i is the probability that the water supplied by the regulator is demanded by farm type i and v indicates transaction costs. Here transaction costs indicate a fixed component on water tariffs considered for costs of implementation and enforcement of the pricing strategy. The only decisional variable in this problem is t, which do not differ among farm types as the regulator is assumed not being in the condition to recognize differences in water uses or to impose a specific quota. Hence, the amount of irrigated land is given as a solution of the farm problem and not linked to any regulatory parameter. Assuming that the cost faced by the regulator to supply water is shared equally across farms regardless of whether or not they are irrigating, the cost recovery constraint in this problem, CR, takes the form of equation (3.4). Conditions in equation (3.4) are added in order to ensure that transaction costs can be covered by the water tariffs and the v is always strictly positive.

If I confine the decision-making problem of the regulator to equation (3.3) and (3.4), the result is rather straightforward. As farmers' profits and regulator's costs are not affected by t, the maximisation problem become the same as minimising t, subject to (3.4). As a result, CR is satisfied always with strict equality.

The level of social benefits achieved will be given by solving the farm problem, with $x_i = x_i^{FR}$, and substituting the result in equation (3.3). The problem of equation (3.3) indicate that if transaction costs are very high, it would be socially preferable not to collect water tariffs.

In terms of farmers' participation, it turns out that there are two regulatory options. First, if tariffs are imposed to everybody in an area, some farms will have positive profit due to irrigation, while the others will have a negative profit. Still everybody will irrigate at the optimal level $x_i = x_i^{FR}$ (which may in principle include an irrigation area equal to zero).

The second option is that farmers can drop out of irrigation, for example by giving up the option to irrigate. If this is admitted, no tariff will apply to them, which implies also that the tariff will be recalculated on the subsample of farmers (with $\pi_i(x_i) - t \geq 0$). An individual participation constraint would not make sense in this setting, as the regulator does not know the individual optimal size of irrigated land, nevertheless this issue is tackled subsequently.

3.4 Incentive tariffs model

This section reflects the case in which the water provider is willing to apply incentive tariffs. The decision to apply incentive tariffs forces to deal with a number of management problems related to their design and to guaranteeing the implementation.

Below, I model the behaviour of the WA whose aim is to maximize the social benefit by incentivizing efficient water use. By assumption, the water regulator is not able to monitor water use directly. Thus, to incentivize rational water use he might apply a tariff linked to some observable characteristics related to water use, such as the type of crops, the type of irrigation system, the irrigated area, etc. As an instance, farmers irrigate different share with different composition of crops, resulting in different crop water requirement for their farm. Eventually it is possible the estimation of individual crop water requirement per irrigated area and determining the tariff for the respective irrigated share in function of water consumption and guaranteeing appropriate water tariffs based in individual generated costs from irrigation.

Differently to the former problem, *ex-ante*, before the irrigation season, the regulator can offer a menu of contracts to farmers. The menu combines the tariff and the share of irrigated area. Farmers may choose the contract they see as more profitable for their farm, engaging in providing different payments and being constrained to a different share of irrigated area.

In line with most of the literature (Moxey et al., 1999; Viaggi, 2010; Arguendas and van Soest, 2011; Galioto et al., 2013), it is assumed the regulator knows farm types served by the irrigation network but he is not in the position to recognize to which type each farm belongs to. Hereby, to incentivise farmers to reveal their true type along with the choice of the contract from the menu, the regulator must set up a pricing scheme which includes the incentives needed to induce farmers to choose the 'contract' designed for the typology they belong to.

Let us now formulate the first part of the problem, where the water regulator attempts to maximize the aggregated social benefit, subject to cost recovery constraints:

$$\max_{\{t_i,x_i\}} S = \sum_{i=1}^{n} \delta_i[(\pi_i(x_i) - c(x_i) - vt_i] \tag{3.5}$$

s.t:

$$\text{CR}_i\text{: } t_i \geq c(x_i) + vt_i \qquad \forall i \in \text{n and } n = 1,2 \tag{3.6}$$

Where, t_i and x_i, indicate the tariff and the share of irrigated land, that are decisional variables, i.e. terms of the contract, that are differentiated among farm types.

The objective function (3.5) is determined by the sum of farm profits, water regulators costs for water provision and transaction costs v. In this assumption, like the previous one, transaction costs per unit of payment request to farmers are taken to be the same between types and proportional to the amount of money taken through the tariff. Transaction costs include costs of administration, implementation, enforcement and monitoring (Smith and Tsur, 1997). Transaction costs related with administration and implementation involve costs the WA face to administer, management or establishment tariffs and collect to water users in a given irrigation sector. Certainly there may be other cases in which transaction costs differ in their form and among types; however these different assumptions are left for future research. In addition, the balance of profits and costs linked to each individual farm type is weighted by the frequency of the farm type δ_i (which can be considered as the total land used by each type, or, with unit size of the farm, as the number of farms in each type).

The cost recovery constraints CR_i, ensures that the cost of water provision incurred by farmers is paid by each farm type in form of tariffs proportionally to costs that each farm type generates (i.e. according to the use of water). Note that this is indexed on i and is hence different from a total costs recovery constraint in which farms may compensate for each other costs, bringing to cross-farm subsidies and perhaps generating adverse incentive on farms' water use (overusing the water resource, especially when water is served via surface irrigation networks). The cost recovery constraint integrates the transaction costs v needed to enforce the incentive tariff strategy. In addition, the cost recovery constraint serves as an economic instrument for guaranteeing the fair share of the water supply costs and transection costs among users. In term of regulatory policy, the CR_i harness farms' willingness to overuse the water resource.

3.4.1. First hypothesis, full information the same water cost functions

We begin with the rather simplified assumption of full information and the same fixed component c of water cost function across farmers. The properties of farmers profit function are $\{\pi_1(x_1), \pi_2(x_2)\}$ where $\pi_1(x_1) > \pi_2(x_2)$ and cost function $\{c(x_1), c(x_2)\}$ where $c(x_1) > c(x_2)$. In reality, most farmers probably do not have c the same due to differences in their characteristics, but at the same time, there are also a number of cases in which farmers use similar technologies, so this hypothesis can be considered as realistic in at least a number of cases. It is supposed that the profit function of the farmer is concave with $\pi_i'(x_i) > 0$ and $\pi_i''(x_i) \leq 0$ and cost function is linear with $c'(x_i) > 0$ and $c''(x_i) = 0$. If the water regulator has perfect information about farms' characteristics, the objective function (3.6) is maximized subject to the cost recovery constraint (CR_i). The Lagrangian is as follows:

$$\max_{\{t_i, x_i\}} S = \sum_{i=1}^{2} \delta_i \left[\pi_i(x_i) - c(x_i) - vt_i\right] + \sum_{i=1}^{2} \mu_i \left[(1-v)t_i - c(x_i)\right]$$

Taking the FCO with respect to t_i and x_i:

$$\frac{dL}{dt_i} = -\delta_i v + \mu_i(1-v) = 0 \qquad (3.7)$$

$$\frac{dL}{dx_i} = \delta_i[\pi_i'(x_i) - c'(x_i)] - \mu_i c'(x_i) = 0 \quad (3.8)$$
$$\frac{dL}{d\mu_i} = [(1 - v)t_i - c(x_i)] = 0 \quad (3.9)$$

By solving equation (3.7) and substituting μ_i in the equation (3.8) the following solution is achieved:

$$\pi_i'(x_i) = \frac{c\prime(x_i)}{(1-v)} \quad (3.10)$$

By solving the equation (3.10) it is possible to determine the optimal irrigated share, marked as x_i^{FB} superscript FB stands for first best solution and substitute it in equation (3.9), from which the optimal level of water tariffs with respect to the type is determined:

$$t_i^{FB} = \frac{c(x_i^{FB})}{1-v} \quad (3.11)$$

If $v = 0$ the equation (3.11) revert to:

$$t_i^{FB^*} = c\left(x_i^{FB^*}\right) \quad (3.12)$$

The outcome of equation (3.12) indicates that the first best (FB) water tariffs cover exactly the water supply costs and the optimal level of farms' tariff is determined when the marginal benefit equals social marginal costs and $x_i^{FB^*}$ stands for first best irrigated share with no transaction costs.

Figure 3.1 illustrates the solution for a single farm and explains the impact of transaction costs on farms' irrigated share and water tariffs. The concave curve indicate the possible combination levels of profit achieved for a given share of irrigated area. The straight increasing line toward the right hand side indicate the costs and the dashed line increasing on x indicate the impact of transaction cost on overall costs, by shifting it at a higher level. All this lines belong to farm type i.

Figure 3.1 illustrates that for increasing level of transaction costs $v > 0$, it is optimal for the regulator to impose farmers a shift in the share of land from $x_i^{FB^*}$ to x_i^{FB} with $x_i^{FB^*} > x_i^{FB}$ and increase the water tariffs from $t_i^{FB^*}$ to t_i^{FB}. This is also visible from the fact that $\frac{c\prime(x_i^{FB})}{(1-v)} > c'\left(x_i^{FB^*}\right) \forall\, 0 < v < 1$. In general, water tariffs are diminished because of the decrease of the irrigated share of land demonstrated with the shift from point A to B in Figure 3.1 but still $t_i^{FB} > t_i^{FB^*}$ due to the impact of transaction costs. This inequality becomes larger as v approaches toward 1. Hence the level of farm's profit become $\pi_i\left(x_i^{FB}\right) < \pi_i\left(x_i^{FB^*}\right)$ and social benefit decreases as well (due to higher costs and lower profit from water use).

In following I will keep this symbols t_i^{FB}, x_i^{FB} to illustrate the first best solution.

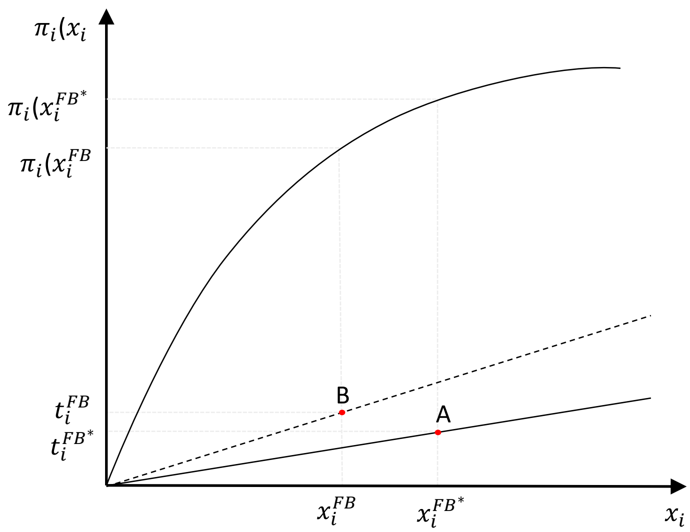

Figure 3.1. First best solution with the variation of costs and profits as transaction costs increase.

3.4.2. Second hypothesis, asymmetric information and the same water cost functions

In this section, is considered a case in which the water regulator has not complete information about farm types identification. Assuming that the water regulator offers a menu of contracts to farmers, but cannot observe if they choose the contract designed for their type or misrepresent themselves in the contract selection. In order to ensure the self-selection of farmers through contract design, the incentive constraints is added and the objective function is modified in the following form (still assuming 2 farm types, 1 and 2):

$$\max_{\{t_1,x_1;t_2,x_2\}} S = \delta[(\pi_1(x_1) - c(x_1) - vt_1] + (1-\delta)[(\pi_2(x_2) - c(x_2) - vt_2] \tag{3.13}$$

$s.t:$

$$CR_1: t_1 \geq c(x_1) + vt_1 \tag{3.14}$$

$$CR_2: t_2 \geq c(x_2) + vt_2 \tag{3.15}$$

$$IC_1: \pi_1(x_1) - t_1 \geq \pi_1(x_2) - t_2 \tag{3.16}$$

$$IC_2: \pi_2(x_2) - t_2 \geq \pi_2(x_1) - t_1 \tag{3.17}$$

The incentive constraint IC_i, ensures that each farmer will find it profitable to choose the contract intended to him. The result of this constrained optimisation problem is a menu of contracts defined by the combination of tariffs t_i and quota of irrigated farm land x_i.

Let's determine the solution assuming that there is no participation constraint; it means that the farmers can then also drop out if they find not profitable to participate. Inspecting the problem of equation (3.13), subject to constraints, however, the first question is if equation (3.16) and (3.17) are binding.

From the assumptions is known that the cost function is assumed to be linear and the same for both farm types this implies that $c'(x_1) = c'(x_2)$ and $c'(x_i) > 0$ and $c''(x_i) = 0$. Farm's profit function is concave with $\pi_i'(x_i) > 0$ and $\pi_i''(x_i) \leq 0$, as well, without loss of generality this assumption considers that type 2 farmer is the one with lowest marginal productivity, i.e. $\pi_1(x_1) > \pi_2(x_2)\ \forall x$ and $\pi_1'(x_1) > \pi_2'(x_2)\ \forall x$.

Given these assumptions and assuming farms' profit function is included in the regulator's objective function, hence the levels of x of the respective ones in the first best are also the private one, once the water cost is internalized. The effect is hence similar to that of a linear volumetric tariffs a more formal explanation is provided in the Appendix 3.4.2.

Things would change if the properties of profit, cost functions or v will change, in the next section the problem is analysed in the case of linear but different cost curves. Other options are beyond the scope of this chapter.

3.4.3. Third hypothesis, full information and different water cost functions

In this section the first best menu of contracts under perfect information is illustrated with reference to different water cost functions and is assumed that $\pi_1(x_1) > \pi_2(x_2)$, but now, differently from the previews analysis, it is supposed that farmers have different cost function with $c_1(x_1) > c_2(x_2)$. This is usually an assumption from the literature as it provides a benchmarking for the alternative information conditions. However, it could be a realistic option when farmers have very heterogeneous irrigated land uses and the WA can assign to each farm a contract type without the need to apply any incentive to discriminate farmers (i.e. of course the resulting incentive scheme will remain rather approximate compared to water metering; the difference will depend indeed on heterogeneity of water use and becomes an empirical issue).

Under this assumption the objective function is rewritten in the following form:

$$\max_{\{t_1,x_1;t_2,x_2\}} S = \delta[(\pi_1(x_1) - c_1(x_1) - vt_1] + (1-\delta)[(\pi_2(x_2) - c_2(x_2) - vt_2] \quad (3.18)$$

s.t:

$$\text{CR}_1\text{: } t_1 \geq c_1(x_1) + vt_1 \quad (3.19)$$

$$\text{CR}_2\text{: } t_2 \geq c_2(x_2) + vt_2 \quad (3.20)$$

With such hypothesis, the cost recovery constraint (CR_i) is satisfied with strict equality for both types, while the IC constraint is not needed (due to the full information assumption). By the assumption that the WA does not need to apply any incentive strategy to discriminate farmers, without loss of generality, this lead to a solution as the one in the section above:

$$\pi_i'(x_i^{FB}) = \frac{c_i'(x_i^{FB})}{1-v} \quad (3.21)$$

By solving equation (3.21), it is obtained the optimal share of irrigated area x_i^{FB}. With respect to irrigated share to each type, from equations (3.19) and (3.20) (solved with strict equality) it is possible to determine the tariff levels for each farm type. Farm's i marginal profit, marginal cost and transaction costs incurred to enforce the incentive pricing mechanism, contribute in conditioning the optimal level of the share of irrigated area. In the special case of $v = 0$, the optimal solution would be the one in which marginal profits equal marginal costs of increasing the share of irrigated land, as estimated in the first hypothesis.

In terms of performance and in comparison with the flat rate water pricing, the strategy under incentive water tariffs is expected to reach higher level of social benefits than the flat rate, while the share of irrigated land is lower, i.e. $x_i = x_i^* < x_i^{FR}$. The real difference from of two water pricing policies is hence an empirical issue.

3.4.4. Fourth hypothesis, asymmetric information and different water cost functions

In this hypothesis, it is supposed that the water regulator is not in a position to identify farm types. The regulator knows the characteristics of two types but does not know which farm is of what type. The regulator might encounter difficulties to discriminate farmers based on observable information and the solution of the first best might not always be applied or lead farmers to cheat about their type (adverse selection) with resulting low efficiency of regulation. Yet, the regulator can set a menu of contracts for incentivizing farmers to reveal their type based on the selection of the contract and still applying water tariffs related to the irrigated share to recover supply costs.

In case of many farmers, the design of the menu of contracts is now an empirical issue. However the direction of the solution can be understood under the assumption of 2 farm types with well behaving profit functions (high productivity type 1 and low productivity type 2) and respecting Spence-Mirrlees condition for profit functions. The Spence-Mirrlees condition is assumed to hold by considering that farm type 1 has a steeper profit function than the farm type 2 and the first derivative of profit function of types 1 is always greater than types 2, i.e. profit curves cross only once.

In this problem, the mechanisms design is at the core of the study in such a way as to identify the means of implementing a given allocation of the irrigated share with respect to the tariff when the relevant information is missing and through the design of the contract menu.

Under asymmetric information, if the WA is unable to observe farm types, there might be an incentive for farmers to declare themselves untruthfully in contract selection. This incentive may arise from the fact that one of the farmer may find profitable to select the contract designed for the other farmer.

If farmers reveal themselves untruthfully, the first best solution is impossible to achieve because water tariffs are not connected to farms' water profits and supply costs. In this case, the involvement of incentive constraints in the objective function become a necessary condition as a mean of forcing farmers to reveal their true type. Under this assumption, the objective function takes the following form:

$$\max_{\{t_1,x_1;t_2,x_2\}} S = \delta_1[(\pi_1(x_1) - c_1(x_1) - vt_1] + \delta_2[(\pi_2(x_2) - c_2(x_2) - vt_2]$$

s.t:

$$CR_1: t_1 \geq c_1(x_1) + vt_1 \qquad (3.19)$$

$$CR_2: t_2 \geq c_2(x_2) + vt_2 \qquad (3.20)$$

$$IC_1\ \pi_1(x_1) - t_1 \geq \pi_1(x_2) - t_2 \qquad (3.16)$$

$$IC_2\ \pi_2(x_2) - t_2 \geq \pi_2(x_1) - t_1 \qquad (3.17)$$

In following three different cases are analyzed:

First: The properties of the profit and costs function of each type are assumed to be $\pi_1(x_1) > \pi_2(x_2)$ and $c_1(x_1) > c_2(x_2)$ and $\pi_i'(x_i) \geq 0, \pi_i''(x_i) < 0; c_i'(x_i) > 0, c_i''(x_i) = 0$. This condition shows that high productivity farmer, type 1, faces higher water cost compared with low productivity farmer, type 2. Differences of costs and profits can have different explanations but in this instance, farmers' profit and cost depends on their characteristics.

Here I evaluate the option whether the first best solution hold even under asymmetric information. Figure 3.2 illustrates a case when first best is incentive compactible at least for some combination of profit and cost functions, in particular due to the distance between the two cost functions, assuming profit functions as given. The π_1 belong to the concave profit curve for farm type 1 which is steeper than that of type two π_2 in each point. The cost line c_1 belongs to types 1 farmer and is greater than the types two c_2. The red point A on the cost function of type's 2 indicate the first best solution for the type 2; the same applies to point B for the type 1.

From the assumptions above, we expect that type 1 behave truthfully because he can get a higher profit (vertical distance between profit and cost function in point B) by paying higher tariffs t_1 and benefit of the higher share of irrigation water allowed by this contract.

If I draw the parallel profit function of type 1 farmer π_1' (high productivity) passing through the point A (fist best solution of the farm type 2) is realized that farm type 1 is not interested in cheating option because the difference between cost that he faces is less than the profit that type one would gain by cheating. This is shown from the profit curve which passes above the red point B which is the solution designed for farm type 1 in the first best. The first best solution still hold and is the same with the one of equal costs introduced above.

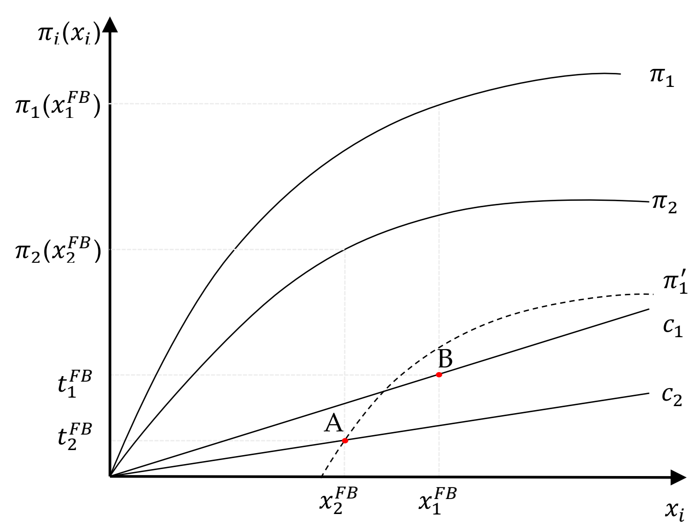

Figure 3.2. First best solution under asymmetric information

Second: Lets still consider the properties of profit and cost function as $\pi_1(x_1) > \pi_2(x_2)$ and $c_1(x_1) > c_2(x_2)$ and $\pi_i'(x_i) \geq 0, \pi_i''(x_i) < 0; c_i'(x_i) > 0, c_i''(x_i) = 0$ and have a case in which the difference of the cost function is larger than in the first assumption above.

For a large enough difference of cost functions (compared to the difference in the profit function), one farmer might have incentives to cheat hence creating a problem of adverse selection.

The illustration of the solution under this assumption is supported by a graphical interpretation in Figure 3.3. Figure 3.3 shows that the difference of the cost function of two types is higher than the one considered in Figure 3.2. This difference is described by the distance of the parallel of the profit function π_1', drawn through the point A that indicate the first best solution of types 2, with the solution concerning indeed type 1 point B illustrated by the vertical bolded black line (i.e. from π_1' to B). In this case, the first best solution is not incentive-compatible anymore because the farm type 1 finds profitable to mimic farm type 2 (i.e. type 1 choses the contract designed for type 2, as the combination of tariffs and irrigated share of type 2 ensures him a higher profit). Therefore, a second best policy needs to be design by the regulator using mechanisms design.

With the purpose of inducing farmers to pay according to generated costs by irrigating, the regulator may be forced to implement some restriction criteria. "Worsening" the pricing condition to at least one farmer (the ones with lower marginal profitability) to dis-incentivize the selection of the wrong contract by the other farmer.

The worsening condition under this assuming implies increasing water tariffs of the farm type 2 in the form of an additional payment (higher overall tariff compared to the first best). This increase is described by the vertical black bolded line illustrated by the distance from point A to A'. The tariff increase is at least up to the level that equalize the distance between π_1' curve and red point B. Hereto if we draw another parallel of the profit curve of farm type 1 indicated by π_1'' through the point belonging to the second best solution of type 2 (point A') it is achieve that the cheating farmer, type 1, under second best is indifferent between contracts because cheating option will not make him better off. The second best contract solution is the one illustrated by the point B for farm type 1 (the same as in the first best) and point A' for type 2 (different from the first best).

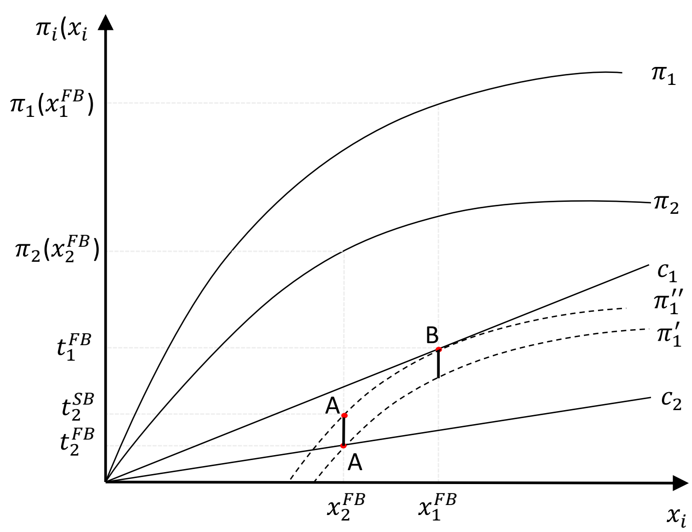

Figure 3.3. Second best solution under asymmetric information

Thus, in second best CR_1 and IC_1 bind with strict equality. Solving the objective function subject to binding constraints the following solution is achieved. Full derivation of theoretical results is provided in Appendix 3.4.4:

$$\pi_1'(x_1^*) = \frac{c_1'(x_1^*)}{1-v} \quad (3.22)$$

$$\pi_2'(x_2^*) = \frac{c_2'(x_2^*)}{1-v} + \frac{v}{1-v}[\pi_1'(x_2^*) - \pi_2'(x_2^*)] \quad (3.23)$$

The solution indicates that the contract designed for the high productivity farm type is the same as in the first best, while the contract designed for the low productivity type has a tariff distortions which correspond to the distance between A and A′ in Figure 3.3. The level of tariff distortion is in the size of the value of the second part of RHS of equation (3.23).

One might think why the regulator do not interfere by adjusting t_1 ?

The t_1 cannot be altered; if the regulator decreases t_1 to make IC_1 or IC_2 binding violates CR_1 setting water tariffs less than costs. If the regulator increases t_1, CR_1 does not bind, becoming strictly greater than costs which actually this action (from Figure 3.3) further incentivize the type 1 toward the cheating option. This occurs because for a higher water cost level, the type's 1 net profit further decreases which drives him in the temptation of taking a cheating option.

This analysis allow us to conclude that the fist best solution is achievable under asymmetric information only in cases where the distance of the costs function is too close between type such that do not motivate farmers to claim higher irrigation water costs otherwise the optimal solution would be the second best. Note however that this is true if transaction costs for monetary transfer are assumed to be zero, i.e. the additional payment asked to the farm type 2 is not costly for the regulator. This assumption is revised in the next case.

Third: under this hypothesis, the properties of the profit and cost function are still considered as in the case above, but it is assumed that the water regulator faces positive (high) transaction costs linked to payments by farmers. As the transaction costs are set linear on tariffs, for increasing transaction costs level, the distance between costs function of farmers will further increase and the cost of monetary transfer for tariff will make costly to increase the payment for one of the farmers.

The additional payment, due to transaction costs coming from the money transfer, would drive the WA to choose different incentive strategy to motivate farmers to select the right contract instead of continuing to increase the tariff until making it prohibitively expensive for the farmer 1. Now the strategy is to propose also a decrease of the irrigated share which is illustrated in Figure 3.4.

The solution under this assumption is illustrated by the black lines shaped from point A to A′ and the decrease of irrigated share of farm type 2 from x_2^{FB} to x_2^{SB}. This move is associated with the establishment of a new level of water tariffs from t_2^{FB} to t_2^{SB} from type 2 and $t_2^{FB} = t_2^{SB}$ for farm 1.

The second best solution is determined at point B for farm type 1 and A′ for type 2. In addition the decrease of irrigated share of farm type 2 is associated with decrease of profits by determined a new level of profit from $\pi_2^{FB}(x_2^{FB})$ to $\pi_2^{SB}(x_2^{SB})$ and for the type 1 the level of profits will be the same as his irrigated share is not altered.

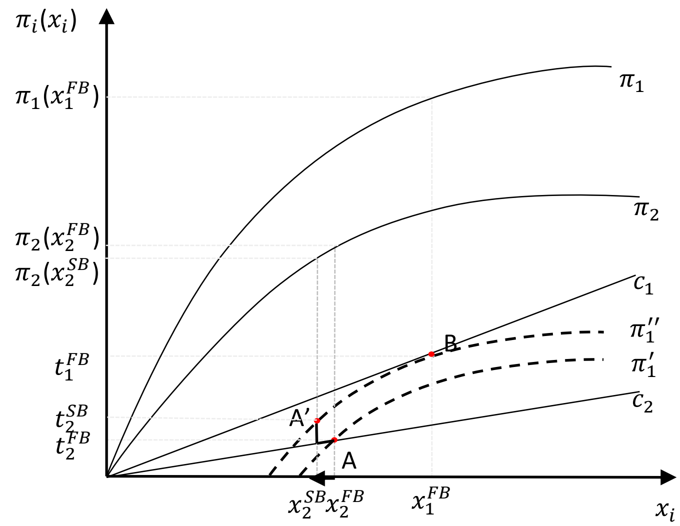

Figure 3.4. Second best solution when overall costs are increased

The main result of this analysis is that the shape of profit functions and the difference of the costs function between types are fundamental in determining the contracts solution. It may be concluded that considering different profit and cost function drive to major changes of the menu of contracts and boost the water regulator to use different strategies to incentivize farmers to behave truthfully. In addition if transaction costs are too high[4] other potential trade-off may arise.

[4] For high cost levels due to transaction costs and water supply costs farmers decrease the irrigated share in a greater size, leading to other contract solution designed by the WA. For example might be a case that binding constraints become $CR_{1,2}$ and IC_1. Solving the objective function (20) under the Kuhn-Tucker conditions analyzed in the appendix 3.4.2 and adjusted with regard to the new form of cost function yield the following solutions (i.e. full solution is provided in Appendix 3.4.5):

$$\pi_1'(x_1^{SB}) = \frac{c_1'(x_1^{SB})}{(1-v)} \tag{3.22}$$

$$\pi_2'(x_2^{SB}) = \frac{c_2'(x_2^{SB})}{(1-v)} + \frac{\mu}{(1-\delta)}\left[\pi_1'(x_2^{SB}) - \frac{c_2'(x_2^{SB})}{(1-v)}\right] = 0 \tag{3.24}$$

The symbol μ in equation (3.24) indicates the multiplier achieved from the Kuhn-Tucker conditions, which is involved to enable the optimization problem to be solved. The multiplier measures the range of change of profits as the irrigated share changes. In addition this variable affects the tariff level set by the water regulator. As well, the value of the second part of the RHS of equation (3.24) influences the additional payment that type 2 suffers as a mean of avoiding the regulator's risk of experiencing an adverse selection problem. If the RHS of equation (3.24) is less than marginal profit in first best solution, naturally the tariff for farm type 2 is higher than in first best, otherwise the opposite would happen. In this line, the additional contribution that farm type 2 will be depended from the value of the second part of the RHS of equation (3.24) and multiplier μ.

In addition the multiplier in (3.24) makes stronger the conflict between additional payment imposed to type 2 and the allocation efficiency, because of reduction of irrigated share of farm type 2 in second best solution.

In term of policy implication, the achievement of first best menu of contracts under asymmetric information indicate that the WA can discriminate farm types through menu of contracts without imposition of costly restrictions in the form of information rents to the societies expense and the designed policy might be imposed without decreasing its efficiency.

However the analyze developed so far may be extended in several ways. A potential development of this hypothesis may be drawn by focusing:

- when the $\pi_1(x_1) > \pi_2(x_2)$ and $c_1(x_1) < c_2(x_2)$ and $\pi_i'(x_i) \geq 0, \pi_i''(x_i) < 0; c_i'(x_i) > 0, c_i''(x_i) = 0$ and checking which farm pretend to behave as another type and under what condition
- by involving a participation constraint and assessing its implication in the contract solution
- by considering fixed and variable costs and evaluating other contract solutions and its effect on social benefits
- by evaluating options under different settings of transaction costs and assessing its implications on the policy design
- an assessment of cases under multi-dimensional of asymmetric information may sharply change the water regulators strategy to find optimal contract solutions

All this points are not addressed in this thesis but may be considering for further development of this analyze.

3.4.5 Effect of participation constraint

Related to the above theoretical analysis in this section it is discussed the case in which the water regulator faces very high water supply costs, which inevitably are converted to a higher water tariffs for farmers. Under such hypothesis, heterogeneity among farm types (i.e. in term of water use or land use) permits for different water productivity among types. This assumption could potentially involve cases that farms returns by irrigation are nearly equal with their water tariffs, or tariffs may prevail over the farm's profit.

In such a setting, the participation constraint, PC_i, guarantees that the tariff paid by farmers should not be greater than their profit received by irrigation.

$$PC_i: \ \pi_i(x_i) - t_i \geq 0 \qquad \forall i \in n \tag{25}$$

Another result from this analysis is that high level of water costs (with respect to transaction costs) influences the decrease of irrigated share of both farmers but the irrigated share of the type 2 is twice effected: first the farmer decreases the irrigated share because of the effect of high transaction costs; second due to interaction of the water regulator to dis-incentivize the type 1 from cheating action. This stands for the fact that above some threshold of overall water cost levels (supply costs and transaction costs), the marginal cost by increasing the water tariffs will be fare greater than the marginal benefit until becoming negative (the marginal benefit can be negative if the costs continue to increase and irrigated share stays unchanged). Hereto the WA cannot offer to the farmer a contract that secures a negative marginal profit, in this manner he interfere by decreasing the irrigated share. The decrease of irrigated share would be up to the level that high productivity farmers is not interested in cheating.

Note that if applied in this way, this constraint forces the model to reduce the tariff rather than dropping participants from irrigation, hence redistributing the tariff to another participant. Thus, I focus here on the WA's strategy and his power to discriminate water tariffs between users.

The modelling contract on variables can be generalised to other contract settings, in this case depends in affordability of water tariffs and profits by irrigation. Herein the farm's ability to support water supply costs is different. For very high water tariffs, farms' willingness to the contribution is reduced and the emergence of the conflict may arise, potentially hampering the implementation of the menu of contracts. If farmers are thought to be unlikely to cheat and obtaining positive benefit, then WA can set the optimal incentive strategy and discriminating water tariffs among water users as described above. If the opposite occurs, the strategies cannot be valid anymore. Because, to avoid the risk of incurring in adverse selection the WA cannot raise the tariff or propose larger decrease of irrigated share, because the farmer cannot afford the rise of water tariffs above the accepted threshold, otherwise his benefit by irrigation will be negative and more likely the farmer would rule himself out of irrigation that means the PC_i is violated.

This condition implies that, paradoxically, when the cost of water is particularly high, justifying the need to differentiate tariffs among users, the rent extraction needed to guarantee farmers discrimination might not be sustainable, failing to discriminate users by the means of pricing instruments.

3.5 Flat rates VS incentive tariffs

The consideration made so far regarding pricing strategies in the absence of water metering reveals that the choice of the pricing method by water regulator is strictly contingent to the reality he face. The economic problem of the water regulator involves the maximization of the social welfare. This is because the social welfare is conditioned of the pricing system adopted by the regulator to recover supply costs.

The flat rate water pricing is innovative in the designed form and perhaps scholars have overlooked its theoretical interpretation, possibly due to its economic inefficiencies. Although yet this tool is commonly used in irrigation districts because of less application complexities even that the water tariffs are equally set among farm types disregarding the water consumption.

With the imposition of flat rates the regulator contributes in maximizing the social welfare simply by guaranteeing the supply of the service. However, the allocation of water resources among farm types is not efficient. That is, the marginal costs faced by the regulator to supply water are higher than the marginal benefits that farmers obtain by irrigating, with the results of wasting water resources and of increasing costs. The economic loss is caused by the inefficiency of the pricing criteria imposed by the water regulator to recover supply costs.

Under incentive water pricing scheme farmers will stop irrigating when their marginal profit by irrigation equalize marginal costs, with respect to the farm type. In this reasoning when marginal profits equalize marginal costs make possible water conservation and lowering costs with respect to flat rates. The restriction effect in the second best would reflect lower level of net profit for the low productivity type. With the imposition of incentive tariffs, the regulator contributes in maximizing the social benefit not simply by satisfying farmers' water requirements but also guaranteeing a rational allocation of costs among users and efficient use of water resource. However, the imposition of incentive tariffs in the absence of water metering implies the occurrence of transaction costs. These costs possibly are explicit (i.e. enforcement costs) and implicit (i.e. rent extraction) and condition the practicality of incentive pricing mechanisms.

Even though with the introduction of incentive pricing mechanisms by the regulator the economic condition of some farmer will become worse off (i.e. low productivity farm type) because of the need to solve any information failure. Certainly, the WA might still chose to apply the incentive pricing scheme if the overall benefit generated with the introduction of the new pricing criteria are higher than the benefit generated by the flat rate scheme.

3.6 Discussion

The aim of the chapter is to provide a theoretical interpretation of incentive water pricing scheme with the focus of maximizing social benefits. The study considers a mechanism design with regard to adverse selection problem and assess the option choice between alternative mechanisms flat rates and incentive tariffs.

The developed incentive-pricing model is similar with Viaggi et al. (2010) and Arguendas and van Soest, (2011) but the mechanism design differ in a conceived form and taken assumptions.

Regarding incentive pricing strategy, its development and implementation regularly is highlighted by the WFD for all member states of EU and frequently are proposed as a strategic tool for water policy (European Commission, 2000; European Commission, 2012; Giannakisa et al, 2016; Exposito and Berbel, 2016 and Lika et al., 2016). The presence of a heterogeneous population of farms managing water resources with common rules partially driven by the progressive enforcement of the WFD principles calls for the need of strategy developments towards incentive oriented water pricing systems, including cases where water is unmetered (Viaggi et al., 2010). In this perspective and refereed to the WFD (Article 9) the research focus on the introduction of the incentive water pricing mechanism when water is served through surface irrigation networks by means of modulating water tariffs with the amount of water use.

Despite the wide suggestions from the EU for the implementation of incentive strategies and tariff differentiation among farms in irrigated agriculture, yet these tools are not rigorously applied in most of the EU regions. Tariff differentiation makes sense if the regulator is supplying water to farmers which are heterogeneous in water uses. The degree of farm heterogeneity in water use and land use is an important implication while designing water-pricing schemes for irrigated agriculture. Frequently condition the feasibility of incentive water pricing and often generates misleading incentives in water use for irrigation.

Figure 3.5 illustrates cases that farmers are characterized by different degree of heterogeneity of water use and land use. The plotted rectangular in the figure displays different combinations of the level of heterogeneity among farm types and implies several implications for the WA for policy design option:

Case 1: If the community of farmers are located downright of the figure (farm types have high heterogeneity of water use and low heterogeneity of the irrigated share) the WA will face the adverse selection problem. This implies a distortion of the variables of the contract for at least one of the farm types. Under this condition a second best solution is achieved. This option is analysed previously where the optimal static incentive tariffs second best is compared with the first best one.

Case 2: For lower level of heterogeneity of water use and land use (down left), the regulator's supply costs among farm types are similar and the need to discriminate tariffs among farm types may not be economically efficient.

Case 3: When the community of farmers is located in up left rectangular, the regulator face farmers with high degree of heterogeneity in land use and less heterogeneous in water use. The fact that farmers are not heterogeneous in land uses and in water use does not justify any tariffs differentiation. With such hypothesis, the regulator can simply apply a flat rate or, better, a tariff proportional to the irrigated area, without applying more complex incentive pricing strategy.

Case 4: If the community of farmers is located in the up right of the figure (high degree of heterogeneity of water use and land use) the applicability incentive pricing strategy is limited mainly by two reasons: a) the WA face very diverse water supply costs among farm types and b) the WA face very high transaction costs for policy implementation. Both aspects impede implementation of incentive water pricing scheme.

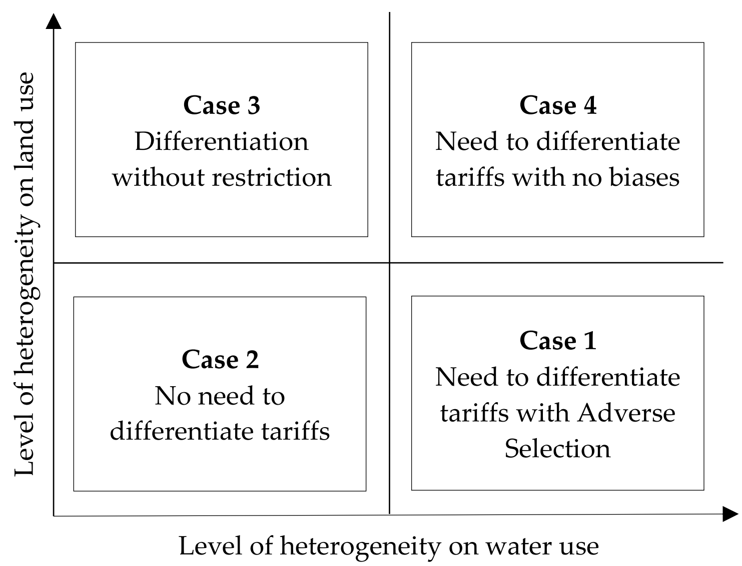

Figure 3.5. The impact of heterogeneity on pricing design options

3.7 Conclusions

The provision of water resource through open canals and the potential inefficiencies in its use by farmers under flat rate pricing motivates the study for the design of alternative pricing strategies that provide incentives for rational use. The study considers a principal agent model which allow the water regulator to develop strategies under full information and hidden information.

Incentive water tariffs and tariff differentiation are auspicious to meet the WFD requirements. However its application not always is favoured because of high level of transaction costs (i.e. costs of implementing the enforcement policies and costs arriving from information asymmetries) which impedes the application of this mechanisms consequently uniform pricing mechanisms are established by water regulators.

Transaction costs significantly affect water regulators mechanisms for imposing a pricing criterion until questioning the implementation of incentive pricing instrument. And with regard to surface irrigation networks, the presence of transaction costs become more evident. In addition costs arising from information asymmetries are fundamental in policy design. For example in absence of water metering the water regulator often is unable to propose a policy at no information rent, expect the special case when the water regulator face a group of farmer with the same or similar water cost function or incentive strategies through contracts differentiation is not necessary. This way, the implementation of mechanism design under hidden informant and its efficiency rely on the regulator's ability to elicit farms' private information at low social cost.

In this respect while designing incentive mechanisms must be considered trade-offs between the costs of revealing hidden information and benefits from applying mechanisms.

Indeed, with regard to above examined cases, the implementation of incentive tariffs in the absence of water metering is strongly affected by composition of farm types surrounding the irrigation network. It is realized that farms' characteristic, level of heterogeneity, profit and cost functions are crucial to the path of developed mechanism.

In case when farmers are less heterogeneous with regard to irrigated share and highly heterogonous on water use function the adverse selection problem occurs. This obstacle is avoided by imposing some restriction criteria to one of frames. This restricted conditions in economic term would be the additional cost that farmers pay as a mean of shrinking the difference between farms water cost in order to not allow them falling in the temptation of adverse selection. This obstacle limits the power of the WA to implement a pricing instrument in a way that tariffs reflect the true cost of water.

Therefore, heterogeneity among farm types is another condition that has a profound impact on the water regulator's decision from implementing one policy to another because of facing diverse water supply costs of the provision of the resource to a group of frames with divers characteristics.

In doing so, it is necessary to incorporate in future policies new techniques and water pricing scheme that guarantee the maximization of social welfare with regard to existing instruments in the way to accomplish the WFD principles. The WFD claim to meet these principles and particularly should not be overlooked, especially when beneficiaries are heterogeneous in water uses.

In this viewpoint, the applied method can be exploited in different perspectives. For instance developing models in the empirical contest to achieve a more evident result coming from real case irrigation districts in order to authenticate the functionality of models. In addition another treatment can be in the environments when the WA faces together the problem of adverse selection and moral hazards, or to identify conditions explaining the reason why the WA's pricing strategies might appear inconsistent with WFD principles in the absence of water metering.

Chapter 4

4. Pricing Unmetered Irrigation Water under Asymmetric Information and Full cost Recovery

Published paper[5]

4.1 Objective

The objective of this study is to design an efficient (social welfare maximizing) pricing scheme in conditions of unmetered water, using empirical information from a region in Albania. This objective was reached by using a mechanism design approach that makes it possible to identify a menu of contracts discriminating among farmers and is implemented assuming that the WUA seeks to motivate farmers to use the optimal amount of water in a context of asymmetric information.

The main originality of the study rests in combining a rather recent and unexplored field of investigation (asymmetric information in water pricing) and a context (Albania) in which water use is still insufficiently investigated. As such, the study is intended to be exploratory in nature, and hence suitable to prepare the background for further applications and improved modelling approaches in other areas with similar conditions.

Chapter is divided into six sections. Subsequently is described the approach and method used, as well as the selected model. The chapter continues with the introduction of case study and presents an overview of the current situation with regard to irrigation in a selected area of Albania and the country as a whole. Then I show model implementation and the identification of a menu of contracts under asymmetric information. In addition the study extend to the interpretation of achieved results. The chapter ends by offering both a discussion and conclusions highlighting how contract theory provides meaningful guidelines for reforming the water pricing system.

4.2 Materials and methods

This research considers a menu of contracts for water charging in an irrigated area. The menu of contracts was compared with flat rate payments, since the flat rate payment is, at present, the only scheme being implemented in the case study area. The menu of contracts is described in the form of a first and a second best solution, in order to consider both the best feasible case (second best) and the best theoretical solution in case of perfect information. The method is based on the application of a menu of contracts as an instrument for the assessment of possible improvements in water pricing in conditions of asymmetric information regarding water use by farmers, and follows the method implemented by a recent paper (Viagg et al., 2010).

[5]This is a published version of the following article: Lika, A.; Galioto, F.; Scardigno, A.; Zdruli, P.; Viaggi, D. Pricing unmetered irrigation water under asymmetric information and full cost recovery. *Water* **2016**, 8, 596

In order to identify the optimal contract scheme, a mechanism design approach was implemented. The purpose of this approach was to identify the appropriate design for a menu of contracts identified by a payment p_i and a share of irrigated area q_i (related to water use) that is able to provide incentives towards (more) efficient water use. On the contrary, in the flat rate case, the payment is determined by the irrigable area and the farmer decides how much land to irrigate independent from the payment (Viagg et al., 2010).

Though rather simplified in this application, the model represents, in essence, a theoretical approach to understanding contractual relationships between the principal and the agent in the case of water resources. The principal is the person who delegates tasks or the party who offers the contract to the agent. The agent is the person who can either take the contract, to perform a task on behalf of the principal or having implications for the principal's objective function, or leave it.

In this context, asymmetric information is a situation in which different knowledge related to water consumption could favour one party as opposed to another. Under perfect information, the regulator knows all the needed information and can set the optimal water quota for each farmer (and set the related price individually). Under asymmetric information, the regulator does not have all of the required information about the farm that would allow this (Galioto et al., 2013, Johansson et al., 2002; Viaggi et al., 2010; Smith and Tsur, 1997; Tsur et al., 2000).

In this regards, asymmetric information can appear in three forms: as moral hazard, when the agent can take an action unobserved by the principal; adverse selection when the agent has some private knowledge about his cost and/or benefit that is unknown to the principal; and no verifiability, which occurs when the principal and agent share, ex post, the same information, but by law no third party can observe this information (Bolton and Dewatripont, 2005; Laffont and Martimort, 2002). In the case studied in this paper, asymmetric information is considered in the form of adverse selection only.

A menu of contracts is created as the combination of a payment p_i with respect to allowed share of irrigated area q_i. By setting the menu, the regulator has the objective to maximize the social benefit $z(q_i)$ represented by the sum over i farm's profit minus the cost of water provision as defined in equation (1), and with i = 1,.. n representing the different farm types. Without loss of generality, it is assumed a Leontief technology for all the production factors concurring in generating the farms profit $\pi_i(q_i)$ and this is expressed as a function of the share of irrigated area q_i for each farm type i.

Farm profits are calculated by considering farms' revenue excluding all costs except for the payment for irrigation water. Revenue is estimated by assessing the yield of agricultural crops cultivated in a given area (kg/ha) multiplied with market price of each crop in (ALL/Kg) is found the revenue (All/ha) for each crop in a given hectare. The sum of revenue of each crop per hectare yield the total revenue per hectare. Now in order to estimate farms profit with respect to irrigated share, from total revenue is subtracted the revenue of non irrigated crop and all possible costa needed for crop production for each farm type.

The cost is given by $cw_i(q_i)$. w_i is the farm's water use function and c is the unit cost of water given in €/m^3 and assumed as not changing with the amount of water used. The total cost of water is dependent on the estimated amount of water demand by each farm type (m^3/ha) and is given in unitary terms €/ha (i.e. further explanation for the estimation of profits and costs are provide in the model implementation section).

The regulator is also assumed to have the obligation of cost recovery, which means that the payments (either p or p_i) need to cover the cost of water provision. Cost recovery can be achieved by individual farms in the case of full information (first best), while it can be achieved only on the aggregate in case of asymmetric information. The concept of full cost recovery in its wider form is better tackled by (Toan, 2016; and Rogers et al., 1998).

The farm's net profit $\Pi(q_i)$ is achieved as the difference between the farm's profit and the associated payment (p_i) for water provision. The payment can, in fact, be either a flat rate, homogenous across farms (p), or differentiated by farm (p_i). Without loss of generality, for simplification, I assume homogenous farm size equal to 1.

Assuming the first best conditions (full information), the water regulator seeks to set the water price in such a way as to maximize social benefits (as given in equation (4.1) below), subject to the cost recovery constraints provided in equation (2).

$$\max z(q_i) = \sum_{i=1}^{n} [\pi_i(q_i) - cw_i(q_i)] \tag{4.1}$$

$$\text{FCR}_i\text{: } p_i = cw_i(q_i) \ \forall \ i \in n \tag{4.2}$$

The best result from a social point of view is achieved where the conditions of equation (4.3) are met:

$$\pi_i'(q_i^*) = cw_i'(q_i^*) \ \forall \ i \in n \tag{4.3}$$

This is the first best solution corresponding to the level of the share of irrigated area for which the marginal profit equalizes the marginal cost of water for society. Equation (4.2) specifies that the full cost recovery principle of the WFD must be met by society as a whole and also by individual farms. In the problem, equation (4.2) is satisfied with strict equality as there is no reason to increase the price of water above the supply costs for society. Equation (4.3) defines the optimal share of irrigated area for each farm type q_i^*.

It is worth noting that if metering had been possible, the same result would have been achieved by imposing a volumetric charge equal to c and this would have corresponded to the marginal profit of water use (expressing both water and profit as a function of the share of irrigated area being irrigated):

$$\frac{\pi_i'(q_i^*)}{w_i'(q_i^*)} = c \tag{4.4}$$

The opposite situation is given by the flat rate payment, in which the regulator cannot impose the share of irrigated area, but only ask for a flat payment p per unit of irrigable area. Each farmer contributing for the provision of water with a flat rate payment will choose to irrigate a share of area that will allow him to maximize profits:

$$\max \Pi_i(q_i) = \pi_i(q_i) - p, \tag{4.5}$$

The maximization problem of equation (4.5) with respect to the share of irrigated area q_i leads to the optimal level of irrigated area, which is the level for which marginal profits equal zero:

$$\pi_i'\left(q_i^{FR}\right) = 0 \tag{4.6}$$

The level of the flat rate payment does not affect farm choices, as farmers irrigate the same share of irrigated area regardless of the level of the tariff. On the other hand, the optimal share of irrigated area is different across farms depending on the farm's i profit function.

The level of social benefits achieved will be given by Equation (4.1), with $q_i = q_i^{FR}$, while the optimal level of the payment will be derived by the total cost:

$$p^{FR} = \frac{\sum_{i=1}^{n} cw_i(q_i^{FR})}{n} \tag{4.7}$$

If the price of water is greater than zero, $c > 0$, then, the share of irrigated area under the flat rate scenario will be greater than the share of irrigated area under the first best pricing scenario (i.e., $q_i^{FR} > q_i^*$ for all farms). The total social benefit will be lower than in the first best scenario, as the share of irrigated area will be higher than the social optimum. The total amount of payments, on the contrary, will be higher, as the overall amount of water used is higher. The payment for individual farmers may be lower or higher than in the first best scenario depending on whether the individual farm is below or above the average water consumption.

I now turn to the third option, which assumes that the water provider does not have complete information about each farm type. More specifically, the provider knows the existing farm types, but is unable to observe each farm type, which could give an incentive for farmers to misrepresent themselves. Under these conditions, the principal cannot assign the optimal contract type to each farm. However, it can still design a menu of contracts that would induce farmers to reveal their type through the choice of the contract. This, however, can entail an information rent for some farmers.

The problem can be now represented as a maximization of equation (4.1), subject to the following constraints:

$$\begin{aligned} &\mathrm{PC}_i\text{: } \pi_i(q_i) - p_i \geq 0 \ \forall\, i \in n \\ &\mathrm{IC}_i\text{: } \pi_i(q_i) - p_i \geq \pi_i(q_{i'}) - p_{i'} \ \forall\, i \in n \text{ and } i \neq i' \\ &\mathrm{FCR}_i\text{: } p_i \geq cw_i(q_i) \ \forall\, i \in n \end{aligned} \tag{4.8}$$

The participation constraint PC_i guarantees that it is not possible to ask farmers for more money than the profit generated from the water provided. The incentive constraint IC_i guarantees that each farmer will have an incentive to choose the type of contract that is designed for him, when profit minus cost of water for farm type *i* is higher than the profit of farm type *i′* which uses the share of irrigated area $q_{i'}$ and pays the price for water as another farm type that is different from *i*, (i.e., *i′*). Finally, the Full Cost Recovery FCR_i constraint guarantees that the cost of water provision is completely paid by each farm type, since the price of water for farm type *i* should be higher or equal to the cost of water used, taking into account the water use expressed as a function of q_i. Full cost recovery in this paper assumes that the WUA is seeking to recover operation and maintenance costs for supplying water to the irrigation network. The total cost of water is dependent on the estimated amount of water demand for each farm type (m^3/ha). Typical operation and maintenance (O&M) costs in the region include payment to water masters to clean and maintain the secondary canals, as well as the managing and distribution of water to tertiary canals to facilitate the withdrawal by farmers. The cost of investment and the primary canals to divert water are not under the WUA responsibility and are not considered in this paper. The state provides assistance to cover the investment and maintenance of primary canals and the diverting water from reservoir to irrigation network.

The maximization problem above, expressing the formulation of the menu of contracts under asymmetric information, does not imply a consistent theoretical solution unless rather restrictive hypotheses are imposed. In this case, I leave to the empirical application to identify the numerical solution able to modulate the payment and share of irrigated area in such a way as to render the farmer indifferent to his or her contract type and to mimicking others. Further illustration is provided in the results section. The above-illustrated models were implemented using GAMS (General Algebraic Modelling System), well know optimization software.

4.3 The case study

Community irrigation management has a long tradition in Albania. Yet during the centralized socialist system from 1945 to 1990, everything formally belonged to the state. It is worth noting that during this period the country invested heavily in irrigation, drainage, reclamation, and land improvement projects, hence increasing the irrigated area to about 50% of the total agricultural land. The post-communist period was characterised by the dismantlement of the previous system and an increase in farmers' distrust toward the central government. At this time, land privatization started rapidly in Albania; the result of which was the creation of more than 400,000 small farms with an average size of about 1.4 ha (Ismaili, 2009).

After 1991 the irrigation network was shattered almost everywhere in the country, and a huge share of firmly irrigated land became non-irrigated due to the destruction of many channels and water distribution systems. The small private farms with insufficient land in many cases have fundamentally changed the character of agriculture, and the role of irrigation and their needs with respect to irrigation have not been clearly communicated. Therefore, the Water Enterprises were not able to better classify irrigated and non-irrigated area and likely failed to distribute water to a relevant share of small farms. The Government of Albania adopted the policy to transfer the operational responsibilities of secondary irrigation canals to water users through Water Users Associations (WUAs), with the operation and maintenance of the primary canals and irrigation reservoirs under the responsibility of the state-owned Water Enterprises.

The establishment of WUAs was in accordance with Law No. 9860 of 2008, later amended and supplemented by Law No. 8518 of 1999 regulating irrigation and drainage. This law establishes a legal framework for creating and operating associations of water users. Moreover, the law defines the structure and organisation of these associations.

The WUA are unions of farmers, operating and maintaining the irrigation distribution facilities transferred to them for this use, and were expected to improve the cost recovery process and develop a more effective water payment system in the long run. The WUAs are responsible for distributing water among their members and collecting water charges; farmers in the area pay for irrigation water provided by a WUA.

The WUA of Çukas, located in the Commune of Lushnja, in central Albania, was selected for the case study and is used as a prototype to discuss the operational methods for improving the performance of irrigation water charges throughout the country. The WUA covers a total area of 5630 ha, out of which the irrigated area accounts for 4405 ha and there are 3218 farmers. The main cultivated crops are: winter wheat, maize, alfalfa, vegetables, beans, greenhouse vegetables, and grapes. The area has an abundance of water, most of which is from open canals, while in recent years additional infrastructures have begun to use pressurized pipes. Even though the water regimes differ, the entire area is characterised by a flat rate pricing system.

The application of water tariffs is uncomplicated, but collection and water management is not without challenges. The water payments are based on the area of land irrigated, independent of the amount of water used, and are set as a flat rate water tariff in ALL/ha (ALL is Albanian currency, which in Albanian is called LEK), (i.e., farmers also pay a yearly fee independent from irrigated area for maintenance of irrigation and the drainage system). Payments are usually made in advance such that water provider can estimate the overall irrigated area as farmers pay and subscribe for irrigated hectare (there are cases in which they do not pay, but irrigate during the season, this could constitute another topic for research and discussion). Accordingly, by receiving payments in advance they are not able to link the water payments with demand and cannot modulate advance payments with water consumption in the season. Water providers estimate only the irrigated hectares and know the crop cultivation in area during the irrigation season. Moreover, there is a conflict between upstream and downstream irrigators in the region, and for this reason, downstream farmers may lack water for irrigation in the peak period.

Given this situation, and knowing that water is unmetered in the case study, for simplicity, I considered the payment method as a fixed payment (flat rate) for the irrigated area. In such circumstances, it was not possible to suggest water payments based on water metering. Accordingly, I propose a scheme based on a menu of contracts so as to link the water payments with corresponding water consumed for the share of irrigated area.

4.4 Model implementation

The implementation of the above-mentioned models require several different farm types to be taken into consideration. In Table 4.1 I present four farm types and illustrate the category that each type belongs to in terms of total land for each type, number of farmers in each type, available land, agricultural land, and the average farm size. According to the data collected through interviews with members of the WUA, I was able to identify the number of different cultivated crops in very fragmented plots, provided as a percentage with respect to the overall cultivated area within the type. Moreover, the level of water consumption of specific cultivated crops was identified for each type and the agricultural production value of each crop for each farm type (quantity produced multiplied by the market price of the product). The farms' profits shown in the table represent the difference of the profit under an irrigation regime with non-irrigation. In addition, the table highlights that farm types 1 and 2 have mixed cultivated crops with the highest level of water consumption, in total, per hectare compared with types 3 and 4, which gives them in return the highest level of yield. Furthermore, the size of the cultivated area of the same crop over types is different and sometimes with different levels of production values, even though farmers are approximately applying the same amount of water. This is plausible as in the region irrigation practices are quite standardized for crop typologies, while other factors, such as land quality, might differ considerably within the region.

Table 4.1. Main characteristics of farm types

Category	**Farm Type 1**			**Category**	**Farm Type 2**		
	0–1 Ha				**1–2 Ha**		
No. of farmers	662			No. of farmers	1495		
Available land	377			Available land	2289		
Agricultural land	307			Agricultural land	2122		
Average farm size	0.46			Average farm size	1.42		
Crops	Cultivated %	Water Use m^3/ha	Profit €/ha	Crops	Cultivated %	Water Use m^3/ha	Profit €/ha
Cucumbers	12	4000	26,785.71	Tomatoes	2	4000	21,428.57
Beans	9	2400	1499.97	Vegetables	5	2800	3750.00
Maize	32	3600	1166.67	Vineyard	2	600	1957.14
Alfalfa	19	2400	590.91	Maize	14	3600	1333.3
Wheat	28			Alfalfa	54	1200	624.68
				Wheat	24		-
Category	**Farm Type 3**			**Category**	**Farm Type 4**		
	2–3 Ha				**>3 Ha**		
No of farmers	828			No. of farmers	233		
Available land	1999			Available land	965		
Agricultural land	1292			Agricultural land	684		
Average farm size	1.56			Average farm size	2.94		
Crops	Cultivated %	Water Use m^3/ha	Profit €/ha	Crops	Cultivated %	Water Use m^3/ha	Profit €/ha
Vegetables	16	2,800	4017.86	Vegetables	6	2800	4821.43
Vineyard	16	600	2935.71	Vineyard	6	600	3914.29
Maize	18	3600	1666.67	Maize	6	3600	1833.33
Alfalfa	35	1200	725.97	Alfalfa	79	1200	759.74
Wheat	15	0		Wheat	3	0	

Table 4.2 illustrates the profit function and the water cost function according to each farm type. The profit function of each farm type $y_i = -a_i q_i^2 + b_i q_i$, is obtained by regressing the differences of the profit obtained for each irrigated crop and the profit obtained for not irrigated crops with respect to the share of irrigated area.

The profit function is concave and the quadratic function is taken to better adapt the shape of the empirical water production functions that are used in many cases in the field of agricultural economics. y_i represents the profit of the farm based on the observed crop mix, with respect to the share of irrigated area on total, and for each farm type. The (a, b) coefficients are the coefficients obtained by regressing the achieved profit with respect to the share of irrigated area. It is worth noting that the profit function is taken as a farm's revenue from cultivation minus expenses for seed or plants, fertilizer, pesticides, and tilling, while costs such as labour and costs of irrigation are not subtracted. The revenue is estimated by considering the yield of each crop cultivated in a given area, multiplying with the respective market price of each crop (ALL/kg).

Based on estimated crop water consumption and unit water cost with respect to each farm type, I estimate the cost of water for each crop, which leads to an estimation of the total cost of the overall area cultivated and irrigated for each specific farm type. The computation of the cost function is adjusted and made based on a consideration of the unit cost of 0.06 €/m^3. This represents the operation and maintenance (O&M) costs. The O&M costs are associated with the supply system from the secondary canals into the farm. Typical O&M costs, in the region, include payment to water masters to clean and maintain the secondary canals, as well as the managing and distributing of water to tertiary canals to facilitate the withdrawal by farmers. A negative cost function is achieved due to the fact that, as following the sequence of crops, their shape is an empirical issue and does not represent the theoretical increasing marginal function.

Table 4.2. Profit function and cost function with respect to share of irrigated area (q_i).

Functions	Farm 1	Farm 2	Farm 3	Farm 4
Profit function	$y = -9973q^2 + 14293q$	$y = -5063q^2 + 7617.6q$	$y = -2094q^2 + 3809.8q$	$y = -1787q^2 + 3572.2q$
Cost function	$y = -103q^2 + 234q$	$y = -88q^2 + 170q$	$y = -68q^2 + 161q$	$y = -59q^2 + 141q$

Incorporating in the model the profit and cost function taken from Table 4.2, I was able to calibrate the models presented overhead with the actual data of the area.

4.5 Results

The results of the simulation for the three different pricing schemes are reported in Table 4.3. Results are expressed in terms of policy parameters (payments and share of irrigated area), profits, net profits, and social net benefit.

The flat rate option shows a social benefit $z(q_i)$ is inferior compared with both first and second best options, while the farm's profit is higher. The net benefit of farm type 1 is higher in the flat rate case. This happens because the farmer may cultivate high water consumption crops and benefit from the fact that payments are set equally among types. This mechanism would favour some farmers that cultivate high water consumption crops and penalize others that consume water in smaller amounts but are forced to pay the same amount as the others. Nevertheless, the overall water payments are higher on average in the flat rate case (as they have higher irrigation shares), compared with first best option.

Table 4.3. Flat rate, first best, and second best water payment scheme.

Farm Types	q_i (%)	p_i (€/ha)	$\pi_i(p_i)$ (€/ha)	$\Pi_i(q_i)$ (€/ha)	$z(q_i)$ (€/ha)
Flat Rate					
Farm 1	0.717	91.262	5121.1	5029.811	11,138.74
Farm 2	0.752	91.262	2864.8	2773.575	
Farm 3	0.91	91.262	1732.9	1641.614	
Farm 4	0.999	91.262	1785.0	1693.738	
First Best					
Farm Types	**q_i (%)**	**p_i (€/ha)**	**$\pi_i(p_i)$ (€/ha)**	**$\Pi_i(q_i)$ (€/ha)**	**$z(q_i)$ (€/ha)**
Farm 1	0.712	114.41	5120.90	5006.47	11,139.24
Farm 2	0.748	77.94	2864.76	2786.82	
Farm 3	0.9	89.84	1732.70	1642.86	
Farm 4	0.993	81.83	1784.90	1703.09	
Second Best					
Farm Types	**q_i (%)**	**p_i (€/ha)**	**$\pi_i(p_i)$ (€/ha)**	**$\Pi_i(q_i)$ (€/ha)**	**$z(q_i)$ (€/ha)**
Farm 1	0.712	114.41	5121.1	5006.47	11,139.24
Farm 2	0.748	104.48	2864.8	2760.28	
Farm 3	0.9	89.84	1732.9	1642.86	
Farm 4	0.993	81.83	1785.0	1703.09	

Looking carefully at the mechanisms behind the results of the second best menu of contracts, it appears that the participation constraints are never binding, the cost recovery constraints are binding for farm types 1, 3, and 4, while the incentive constraint is binding for farm type 1 only. This means that in the second best menu of contracts, the water regulator can adopt a strategy that offers farmers the opportunity to irrigate the optimal share of irrigated area. This indeed happens for farm types 2, 3, and 4, all of which will opt for the contract targeted to their type. The opposite holds for farm type 1, which has the highest water payment, and who would try to misrepresent himself by mimicking farm type 2. Therefore, to make farm type 1 indifferent to the contract that belongs to him and the contract designed for another farm type, an increase in the water payment for farm type 2 is made, which is illustrated in Table 4.3, second best solution. Other farmers, namely types 1, 3, and 4 pay equal as in the first best solution (considering other options, the range of farmers that cheat during the contract selection may change (i.e. for different profits and costs)). The solution reached shows that all farm types still irrigate up to the level that marginal profit equalizes the marginal cost of supplying water (as seen in equation (3)), which means that there are no additional supply water costs for the water provider and the same water cost level is incurred. However, the water payment differs at least for farm type 2. This increase in farm type 2's water payment does not affect the social benefit, which will be the same as in the first best solution. Nevertheless, this causes a decrease in his net profit, which is lower compared with first best solution $\Pi_2(q_2^{FB}) \geq \Pi_2(q_2^{SB})$ (the $\Pi_2(q_2^{FB})$ and $\Pi_2(q_2^{SB})$ indicate the farm type 2's net profit in the first and second best menu of contracts. This result is connected to the assumption that the higher payment in itself has no additional social cost; otherwise a need for additional incentive payments would also be accompanied by a change in optimal share of irrigated areas.

A sensitivity analysis is carried out to evaluate farms' behaviour under an increase in water costs (Table 4.4 and Figures 4.1–4.4). I assume water cost levels from 0.00 €/m³ to 1.20 €/m³, in spite of the fact that the upper levels are rather unrealistic in the area. In this way, I show potential real life results in the range below 0.50 €/m³ (considering a potential future increase of water costs also in a context of climate change and higher probability of water shortages even in water-rich areas), while the water cost levels above 0.50 €/m³, rather far from real-life values, are used as a more academic exercise in order to better show the functionality of the models proposed and to highlight the role of asymmetric information, as well as to clearly show the difference between the first best and second best option.

As expected, the increasing level of water costs results in an increase in water payments for farmers and a decrease in the farm's net profit. Under a flat rate scheme, where this higher cost is not transferred to farmers, the demand for irrigation water remains at the optimal level when the water costs increase, but there is an increase in water payments for farmers.

Under the menu of contracts option, the regulator responds to the higher water costs by reducing the share of irrigated area allowed in the contracts, which leads to a reduction in water use. Also under the menu of contracts, the water payment increases as the water cost increases, but shrinking the share of irrigated area is associated with diminishing compensation payment (which is reasonably associated to a decreased irrigation share). Table 4.4 illustrates the corresponding social benefit for each pricing scheme for different water cost levels. Over the variation of water cost levels, the total social benefit decreases. With water costs equal to zero, the three pricing schemes are equivalent. By increasing water costs, a difference becomes evident between flat rate and the other two options, and this difference becomes greater as the water cost increases. This is because the flat rate option does not transfer the costs to the farmers.

Table 4.4. Range of social benefits as water costs increase $z(q_i)$.

Water Cost €/m³	Flat Rate (€/ha)	First Best (€/ha)	Second Best (€/ha)
1.20	4202.79	4616.93	4476.52
1.08	4932.89	5229.12	5019.25
0.96	5662.99	5873.94	5686.55
0.84	6393.09	6540.81	6536.44
0.72	7123.19	7223.55	7219.44
0.60	7853.29	7918.29	7918.29
0.48	8583.39	8622.45	8622.45
0.36	9313.49	9334.24	9334.24
0.24	10,043.59	10,052.33	10,052.33
0.12	10,773.69	10,775.77	10,775.77

0.00	11,503.79	11,503.79	11,503.79

Concerning now the difference of social benefit between the first best and second best, this occurred due to the fact that for some water cost levels, in the second best solution, farmers decrease the share of irrigated area more than in the first best, which corresponds to a lower level of social benefit. In addition, for water cost level above 0.60 €/m^3, the difference becomes more evident.

Figure 4.1, given below, illustrates the range of the share of the irrigated area as the water cost increases on the primary axes, and the trend of the social benefit on the secondary axes for each pricing option. The term IRR (i.e., IRR-Flat Rate) on the table stands for the irrigated share provided as averages across farms, and SB stands for social benefit. Under flat rate of water pricing option (green line), farmers do not decrease the share of irrigated area for the fact that their payments are not directly linked with the amount of water used. Under the menu of contracts, this is different: farmers decrease the share of irrigated area as the water cost increases. Under the first best option, the decrease of the irrigated share varies in the range 0%–15% while, under second best, farmers decrease the irrigated share even more, in the range 0%–52%. The decrease of the share of the irrigated area is associated with decreases of the farms' profits.

Figure 4.1 also provides the trend of the social benefit under different water pricing options; as expected, the social benefit decreases as the water cost increases in all cases. However, in the first part up to 0.6 €/m^3, the range of decrease of the social benefit appears to be in the same portion for all pricing options (actually, it differs by a very small amount); above 0.60 €/m^3 the change starts to be more evident. This occurs due to the fact that up to a water cost level of 0.60 €/m^3 farmers do not decrease the irrigated share as much, which does not reflect the decrease of the social benefit; above 0.60 €/m^3 the differences in decreasing the social benefit become more distinguishable.

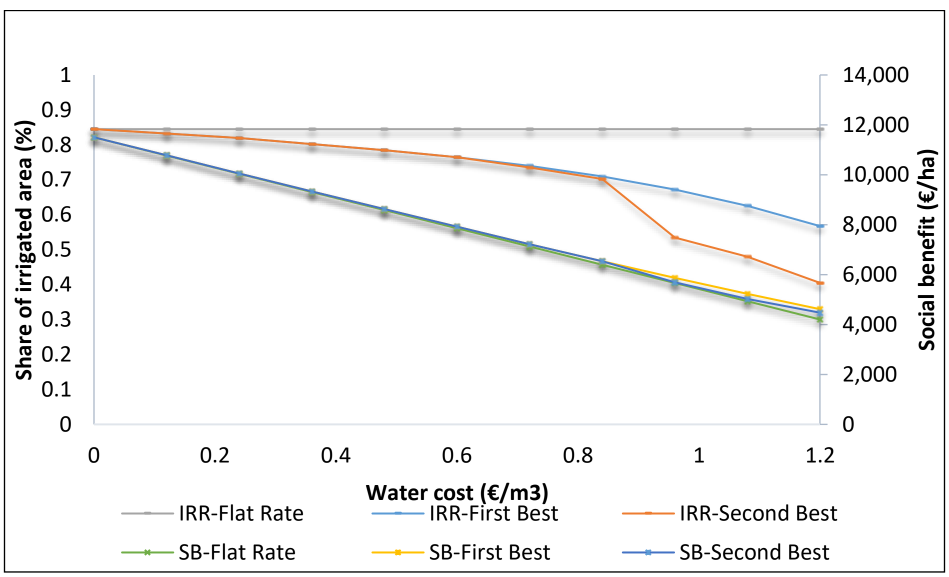

Figure 4.1. The IRR-Flat Rate, IRR-First Best, and IRR-Second Best curves illustrate the trend of the share of irrigated area. The SB-Flat Rate, SB-First Best, and SB-Second Best curves illustrate

the trend of the social benefit considering three water pricing scenarios, as the water cost increases. IRR, irrigated share provided as averages across farms; SB, social benefit.

A graphical illustration is provided in Figures 4.2–4.4 to show the trend of a farm type's net profit under different water cost levels with respect to different water payment options.

In all water pricing options, the increase in the water cost would reduce the farm's net profit. Regarding the flat rate water pricing scheme, Figure 4.2 shows that the percentage decrease goes up to 38% for farm type 1 and 100% for farm types 3 and 4, which means that farm types 3 and 4 stop irrigation at some levels of water cost increase.

Under the first best (Figure 4.3) and the second best menu of contracts (Figure 4.4), the increase of water costs decreases a farm's net profit, as in the flat rate case. In the first best option, the range of percentage decrease goes up to 40% for farm type 1 and the highest level of a net profit decrease occurs to farm type 3, with a decrease up to 92%. In the second best option, the percentage of decrease of the farms' net profit is even greater for some farmers, for farm type 1 the net profit decreases up to 40%, as in first best option, and farm type 4 experienced the highest level, with a decrease up to 100%.

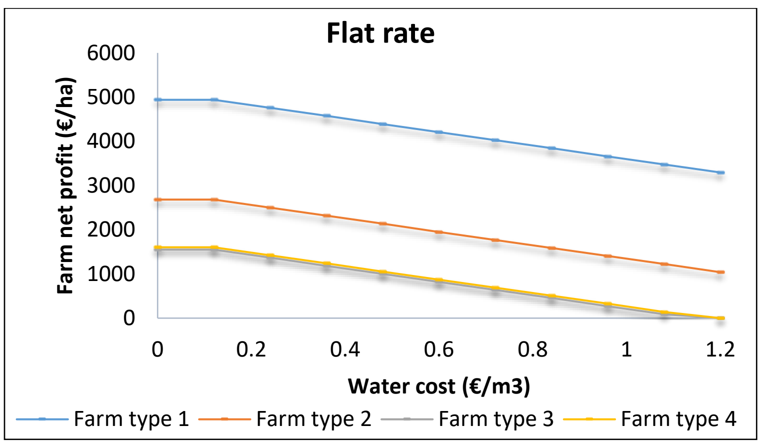

Figure 4.2. Farm net profit under flat rate water pricing scenario

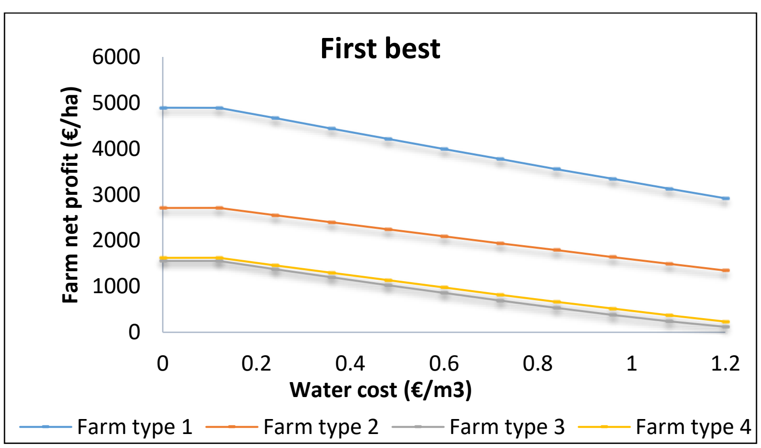

Figure 4.3. Farm net profit under first best water pricing scenario

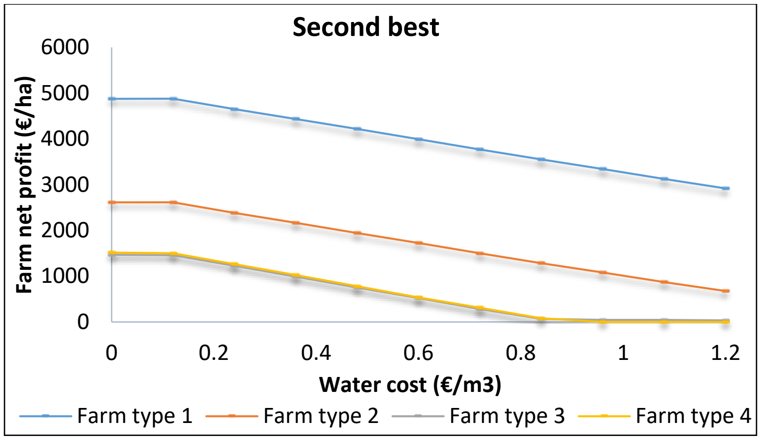

Figure 4.4. Farm net profit under second best water pricing scenario

4.6 Discussion and conclusions

This paper discusses the option of applying a menu of contracts in Çukas (the case study area in Albania) for irrigation water pricing. The aim of the study was to define an efficient price scheme under asymmetric information using a principal-agent model. In particular, I considered the potential of the menu of contracts by using a mechanism design approach which thereby made it possible to identify a menu of contracts discriminating among farmers and to implement it in such a way as to assume that the WUA seeks to motivate farmers to use the optimal amount of water in a context of asymmetric information, and to compare it with the flat rate water pricing scheme currently applied in region. Few scholars have focused on the theory of water pricing through the principal-agent model. This paper follows a method proposed by recent studies, notably (Galioto et al., 2013; Viaggi et al., 2010).

I acknowledge the weaknesses of this approach and the limitations in proposing straightforward applications of the results to real life pricing. The quality of policy design is generally dependent on the data available and the tools used. A significant limitation encountered was that the respective offices in the case study area were not able to provide the full information required for the study with regard to irrigation water (for example, more accurate information regarding costs and benefits of farmers in order to better define the profit and cost function with respect to each farm type). An additional limitation is that the demand functions were obtained by considering revenue with and without irrigation for the same crop rather than proper demand functions based on water production functions and the crop mix. These simplifications significantly affected both the design of the menu of contracts and the results.

Despite these limitations, the method may hint at ways of mitigating the problem of asymmetric information, even in cases of unmetered irrigation water, since the price discrimination provides incentives for farmers to choose among contracts. Nevertheless, the results show that using a menu of contracts (i.e., second best) characterised by variability of water payments to different farm types, may improve the overall social welfare derived from irrigation water use. On the other hand, the flat rate scheme only provides a water payment to recover costs, thereby providing no incentives for efficient water use and conservation. Moreover, the menu of contracts provides a useful framework to study the problem of water pricing in cases of unmetered water.

In practice, however, it may be difficult to propose a menu of contracts to water users in Çukas (Albania) because of the novelty of this approach compared with the traditional method. Even if I am aware of the difficulties inherent in this methodology in terms of application and implementation, my intention was to provide a useful method for the creation of mechanism design through contract theory. Furthermore, the theory of menu of contracts could encourage policy makers to consider this new pricing strategy as an option and to use insights derived from this approach in improving the irrigation system.

The application of this method and the realisation of tangible outcomes can be reached by implementing it with a better endowment of data. Moreover, the method used can be improved in the near future by estimating more reliable demand functions. In addition, further research could be undertaken by theoretically developing the framework for designing payments under asymmetric information. This would go a long way towards analysing the feasibility of the model in real life conditions and towards evaluating its effectiveness.

Chapter 5

5. Water Authorities' Pricing Strategies to Recover Supply Costs in the Absence of Water Metering for Irrigated Agriculture

Published paper[6]

5.1 Objective

The main objective of this paper is to provide an incentive water pricing strategy in the absence of water metering by considering the presence of moral hazard and transaction costs. In addition, the incentive pricing strategy is compared with the flat rate model and an empirical example is provided to provide an assessment of expected impacts.

The chapter is organised in four sections. The second section is divided in six subsections. The first one provides a brief background and literature; the second describes the model setting; the third describes the flat rate water pricing scenario; the fourth provides the incentive water pricing scenario by considering the case of full compliance and perfect detection; the fifth subsection describes and analyse the presence of moral hazard problem. The last subsection evaluates flat rate and incentive tariff strategies. Section three describes an empirical example and involves two subsections: the case study and model parameterization are described in the first one and the results achieved are described in the second. The chapter ends with section four that provides a discussion, conclusions and possible extensions of the model.

5.2 Materials and methods

5.2.1. Background literature

In the case of a surface irrigation network, the water provider usually applies flat rates, especially when there are no limitations to the availability of water resources and differences in water uses cannot be, or are too costly to be, assessed. With flat rates, users are taken to have similar access and are charged equally across farms (Molle and Berkoff, 2007) i.e. the tariff is the same per hectare of land for all farms. Indeed, the regions supplied by surface irrigation network usually are very large and comprise huge extensive farms irrigating only a small quota of the cultivated agricultural land or specialized small fruit and vegetable farms irrigating most of the cultivated land. As a result, farmers benefit differently from the water supplied by the WA and pay tariffs as a part of total overall water supply costs which are, however, proportional to the total agricultural farmland and not to the irrigated farmland. Moreover, flat rates do not usually incorporate the environmental costs generated by irrigation activities, which threaten the status of water resources, especially due to nutrient leaching. Under such conditions, missing to link tariffs to water use and disregarding the total costs generated by the use of water resources, the

[6] This is published version of the following article: Lika, A., Galioto, F., Viaggi, D. Water authorities' pricing strategies to recover supply costs in the absence of water metering for irrigated agriculture. *Sustainability*, **2017**, 2210

water provider cannot expect that tariffs provide incentives to farmers to rationalize the use of water for irrigation. Tariffs play just the role of recovering supply costs.

A typical agency problem surrounding the use of water resources in agriculture arises when the WA decides to apply incentive tariff schemes for the water supplied through surface irrigation networks. In this case, farmers may own private information on water use which is unknown to the WA (e.g. water use profitability) and they may take opportunistic actions totally or partially undetected by the WA (e.g. a different amounts of water withdrawn compared to that agreed or assigned to the farm). These actions lead to increasing the WA's water supply and the management costs (Fraser, 2013).

In particular, when a certain amount of irrigation water is assigned or self-reported by the farmer, the WA often faces difficulties in verifying whether farmers are complying with the amount reported. Under such condition, monitoring is costly and not fully effective. To avoid non-compliance, the WA might apply a sanction to farmers (Hart and Latacz-Lohmann, 2005). Thereby, farmers' actions remain solely the choice of the farmer, but depending on incentives to take the action. These incentives against cheating not only depend on the sanction, but also on the efficacy of monitoring in detecting their action. In this respect, different technology options may be available. Direct monitoring by WA operators may be very costly, while the use of information technologies could be much cheaper and hence help to discourage cheating and free riding due to information asymmetries.

If the WA monitoring capacity is perfect (the WA is in a position to perfectly detect who is complying or not with the agreed amount of water at zero cost) the incentive mechanism is fully efficient and non-compliance is avoided with no sanction. If this is not the case, the WA needs to design an incentive water pricing scheme, including a monitoring and sanctioning strategy, to boost compliance (Rothkopf and Pibernik, 2016). The optimal monitoring strategy depends on the cost needed to enforce such mechanisms and on the effect on water use efficiency.

Given this context, the model below simulates the behaviour of a WA the aim of which is to maximize the social benefit incentivizing rational water use. It is considered that the water authority is acting on behalf of a group of farmers: it seeks to maximize total farmer profits minus the costs of water provisions (including environmental costs); it also shares costs among users according to water use and may provide sanctions for non-compliant farmers. In addition, to incentivize rational water use the WA may apply incentive tariffs linked to some observable characteristics correlated to water use.

In order to analyse these contract design issues, the methodology is developed based on the Principal-Agent Theory (Bolton and Dewatripont, 2005; Laffont and Martimort, 2002), taking into account potential instrument design based on the asymmetric information literature. Specifically, the analytical approach developed in this study makes it possible to estimate the costs faced by the WA in setting up different pricing mechanisms in those circumstances where water is not metered.

5.2.2. Model setting and flat rate pricing scheme

The sequence of decisions for the flat rate scenario works as follows: 1) During the irrigation season farmers take decisions regarding how much to irrigate; 2) At the end of the irrigating season the regulator recovers supply costs by imposing a flat rate. In this framework, farmers' decisions with respect to water uses is independent of the cost faced by the water regulator to supply the service; on the contrary, the supply cost and hence the tariff depends on water uses. This occurs because farmers sign for water uses *ex ante*, while decisions on pricing are taken by the regulator *ex post*, at the end of the irrigation season, and depend on what farmers have subscribed to *ex ante*.

Consider that farm type i when $i = 1, \ldots, n$ has a cultivated area with different crop water requirements. Without loss of generality is assumed that each farm has a land area equal to 1. Supplying the water to the farm is costly for the WA $c(x_i)$ and the farmer, as a result of irrigation receives a profit of $\pi_i(x_i)$. A quadratic production function is assumed for input factors concurring in generating the farms profit $\pi_i(x_i)$ with regard to a cultivated crop. The water supply cost function $c(x_i)$ represents total water costs for delivering the water to the farm for irrigating each crop of farm type i. The character x_i indicates the share of irrigated area of the farm type i. From now on, the share of irrigated area x_i is consider as a proxy for water use, while farm profits and regulator supply costs are assumed to be a function of the share of irrigated area and are assumed to be increasing and concave in x with $\pi_i'(x_i) > 0$, $c'(x_i) > 0$ and $\pi_i'(x_i) \leq 0$, $c'(x_i) \leq 0$

Under such a condition, a rational farmer will choose to irrigate a share of area that will allow him to maximize his profit:

$$\max \pi_i(x_i) \tag{5.1}$$

The irrigated share is the decisional variable and is the percentage of total cultivated area of the farm. Thus, the profit function is a per hectare profit function. Then, the optimal level of the farm's irrigated share x_i is the level for which marginal profits equal zero: $\pi_i'(x_i) = 0$. Let us call this level x_i^{FR}.

Ex post, the regulator must recover supply costs by imposing water tariffs to farmers. It is also assumed that the WA does not face any enforcement and monitoring costs, nor other transaction costs. Moreover, the WA, by assumption, is not in a position to monitor the farms' water use and consequently to allocate supply costs among farmers based on actual uses.

Under such condition, the per hectare tariff paid by farmers will be:

$$t^{FR} = \frac{\sum_{i=1}^{n} c(x_i^{FR})}{n} \; \forall \, i \, \in n \tag{5.2}$$

Where, t^{FR} is the tariff paid by each farmer $i \in n$ and the superscript FR indicate flat rate t^{FR}. The farmer pays the water tariffs based on the overall water supply costs $c(x_i^{FR})$ and there is no link between farms' water consumption and the tariff paid to the regulator.

5.2.3. The incentive pricing scenario

The absence of water metering does not prevent the WA from implementing indirect incentive tariffs. The WA could regulate water uses by connecting tariffs to the share of irrigated land. The effectiveness of the strategy may depend on the WA's ability to monitor farmers action. The quality of monitoring and the relevant costs affect the practicality of the incentive tariffs.

The sequence of decisions for the incentive pricing scenario works as follows: 1) Before the irrigating season the regulator sets the pricing level per hectare of irrigated farmland and the farmer informs the regulator of the area he intends to irrigate; 2) during the irrigating season the regulator monitors the agricultural region served by the water supply network to check whether or not farmers are complying with their initial proposals; 3) at the end of the irrigating season farmers pay the agreed tariff to the regulator plus a sanction if it determined that they were not compliant during the irrigating season. Under such a hypothesis, farmers' decisions on land use are conditioned by the tariff the regulator sets to recover supply costs. The implementation of incentive water pricing by the regulator would generate transaction costs, v. The transaction costs are assumed to be the costs needed to implement the new incentive pricing criteria and to monitor water users.

In the following sub-sections, a principal-agent model is set up in which the goal of the regulator is to maximize the social benefit. Specifically, in the first subsection I disregard the moral hazard problem and deal only with presence of transaction costs under the assumption of full information and discuss the equilibrium solution obtained. Then, I relax this assumption by introducing the conditions that favour the occurrence of moral hazard and the instruments that might be used to avoid such a risk, and discuss again the new equilibrium solution.

5.2.4. Incentive pricing with full compliance and perfect detection

In this section is analysed the contract offered to the farmer that combines the irrigated share x and the water tariff t, assuming the WA fully observes the farm's action. In such a situation, the WA's problem is to recover water supply costs.

$$\max z = \pi(x) - c(x) - vt \tag{5.3}$$

s.t.

$$\text{CR: } t \geq c(x) + vt \tag{5.4}$$

The maximization of social benefit z makes it possible to maximize the aggregate profit (i.e. the WA's and farm's profit) and involves the farm's profit $\pi(x)$, the WA's water supply costs $c(x)$ and transaction costs v linear on tariff t. The objective function is subject to a cost recovery constraint (CR), indicating that the water tariffs must cover at least the water supply costs and the transaction costs generated by implementing incentive water pricing.

Given the transaction costs generated by the water tariff, it can be supposed that the CR constraint is always binding in optimum. Rearranging equation (5.4) is possible to determine the level of the tariff t, which is in function of the irrigated share and transaction costs.

$$t = \frac{c(x)}{1-v} \tag{5.5}$$

Substituting in the objective function equations (5.5):

$$z = \pi(x) - c(x) - v\left(\frac{c(x)}{1-v}\right)$$

And taking the derivative with respect to x, the First Order Condition (FOC) yields the following optimal solution:

$$\frac{dz}{dx} = \pi'(x) - c'(x) - v\left(\frac{c\prime(x)}{1-v}\right) = 0$$
$$\pi'(x) = \frac{c\prime(x)}{(1-v)} \tag{5.6}$$

By solving equation (5.6), where the farm's marginal profits $\pi'(x)$ equal marginal costs $c'(x)$ weighted by the level of transaction costs v, it is determine the optimal share of irrigated land x which can be therefore replace in equation (5.5) to determine optimal water tariff t.

The result of equation (5.6) implies that when transaction costs are high the optimal irrigated share decreases and the tariff increases. The optimal level of x reaches its maximum when $v = 0$, in the absence of transaction costs, and the marginal benefit equals the marginal social cost of water.

5.2.5. Incentive pricing with effective detection

In the absence of water metering, under the incentive pricing scenario the farmer's decision may either to participate and comply with the agreed rules or to participating and cheat, e.g. irrigating higher irrigated share than this allowed by the contract. Compliance implies a disutility for the farmer. This disutility is equal to the difference between the maximum profit that the farmer would obtain in the absence of incentive pricing and the profit the farmer would obtain by irrigating the share of irrigated area declared at the beginning of the irrigation season, $\pi(x^{FR}) - \pi(x)$. If the farmer chooses not to comply with his statement, his disutility would be equal to zero.

With the purpose of discouraging false reporting, the regulator monitors farm actions. If the regulator deems that there are no problems, the farmer will pay to the regulator the agreed tariff t. Otherwise, the farmer is obliged to pay a sanction, ε, in addition to the tariff. Assuming that the farmer is risk neutral, sanctions can be considered the utility that the farmer obtains when complying with the rules.

In this assumption it is considered that monitoring costs are involved in transaction costs and no explicit costs from monitoring. The monitoring strategy introduced by the WA to detect farmers' actions in the absence of water metering is not perfect. That is, the WA might fail to detect farmers' behaviour. Without loss of generality, a discrete probability setting is introduced, where: P_0 is the probability that the farmer is found to comply with his statement when he is actually complying and P_1 is the probability that farmer is found to be non-compliant with his statement when he is actually not complying. Likewise, $(1 - P_0)$ and $(1 - P_1)$ are the probabilities of failing to capture the right signal. The incentive strategy is a viable strategy when P_0 dominates $1 - P_1$, otherwise the prerequisite to implement an incentive pricing strategy fails. That is, the range of possible values for P_0 is $(1 - P_0) < P_0 < 1$ and for $(1 - P_1)$, $0 < (1 - P_1) < P_0$.

In addition, the sanction applied by the regulator to dis-incentivize non-compliance is assumed to contribute to increasing transaction costs. With such a hypothesis, the following problem includes a sanction item in the objective function and an incentive compatibility constraint (IC) besides the CR constraint discussed above.

$$\max z = \pi(x) - c(x) - v(t + \varepsilon) \tag{5.7}$$

s.t:

$$\text{CR: } t \geq c(x) + vt \tag{5.4}$$

$$\text{IC: } \pi(x) - (1 - P_0)\varepsilon \geq \pi(x^{FR}) - P_1\varepsilon \tag{5.8}$$

Where: P_0 and P_1 represent probabilities of detection, $\pi(x)$ indicates the farm profits in function of irrigated share, t indicates the tariff and ε represents sanction. The IC guarantees a utility for compliance which is higher than the utility of being non-compliant. The left hand side of the newly introduced IC is the reduced form of $P_0(\pi(x) - t) + (1 - P_0)(\pi(x) - t - \varepsilon)$. Likewise, the right hand side is the reduced form of $P_1[\pi(x^{FR}) - t - \varepsilon] + (1 - P_1)(\pi(x^{FR}) - t)$. The reason behind this constraint is that in order to make sure the farmer complies with the rules, the benefit obtained by the farmer when he observes the rules must be greater than the benefit obtained by the farmer when he does not observe the rules. The IC can be further rearranged highlighting that to incentivize compliance, the utility the farmer obtains by complying with rules, $P_1\varepsilon - (1 - P_0)\varepsilon$, must be higher than the relevant disutility, $\pi(x^{FR}) - \pi(x)$. It is worth noting here that the utility that the farmer obtains by complying with rules is influenced by the fact that the farmer has some probability of being detected as non-compliant.

Overall, differences in utilities are conditioned by the WA's monitoring capacity (probability to correctly detect farmers' behaviour) and by the magnitude of the losses experienced when complying with rules.

When the IC constraint holds with strict equality it is possible to estimate the level of the sanction:

$$\varepsilon = \frac{\pi(x^{FR}) - \pi(x)}{P_0 - (1 - P_1)} \tag{5.9}$$

The level of sanction is obtained by the difference between the profit obtained with no restriction on irrigated land use $\pi(x^{FR})$ and the profit obtained with restriction on irrigated share $\pi(x)$ divided by the difference between the probability that compliance is detected P_0 when the farmer is compliant and the probability that the farmer is detected compliant when he is non-compliant $1 - P_1$.

The following solution is obtained by substituting in the objective function ε determined from equation (5.9) and t determined from equation (5.4) when both constraints are satisfied with strict equality and taking the FOC with respect to x:

$$\pi'(x) = \frac{c\prime(x)}{\left(1 + \frac{v}{P_0 - (1 - P_1)}\right)(1 - v)} \tag{5.10}$$

The equilibrium reached in equation (5.10) (see Appendix 5.2.5) is contingent of probabilities of detection and transaction costs. The variation of its components influence the optimal level of the irrigated share, the level of tariff and the level of the sanction, contributing in conditioning the magnitude of the social benefit. By increasing the accuracy of monitoring (probability to correctly detect farmers' actions), farms' irrigated share decreases, the tariff decreases and the sanction needed to discourage non-compliance decreases.

Given the transaction cost levels, the maximum impact on a farm's irrigated share is obtained when $P_0 = 1$ and $(1 - P_1) \cong 0$, that is, when monitoring is perfect. The farmer is complying with the rules of the contract and the WA's capacity to determine that farmer is complying with the rules is maximized. Under such a hypothesis, the equilibrium solution is subject to the level of transaction costs. The higher the level of v the lower the irrigated share.
On the contrary, when $P_0 \cong (1 - P_1)$ then $\pi(x)' \cong 0$. That is, the equilibrium solution regresses to the flat rate case as the incentive mechanism has no effect on irrigated land use.

Finally, for $(1 - P_1) < P_0 < 1$ and $0 < (1 - P_1) < P_0$ there are infinite intermediate solutions between the above-discussed probability scenario limits.

With reference to transaction costs, with increasing transaction cost levels the tariff level is increased from equation (5.4) and, as a result, increases the marginal profit level in equation (5.10) and decreases the share of irrigated area. The farmer might be wishing to decrease the irrigated share to pay less. Under such conditions, the cheating option may become more attractive and the moral hazard problem is more likely to prevail. As a reaction, the WA increases the sanction to discourage non-compliance. In addition, the value of the sanction is also influenced by the accuracy of the instruments adopted by the WA to monitor uses and increases with the reduction of the accuracy level.

5.2.6 Evaluating strategies under the two pricing schemes

As discussed above, the WA might face additional transaction costs and suffer some inefficiency due to imperfect monitoring to implement an incentive pricing strategy in the absence of water metering.

Because of this, the WA might decide to keep the flat rate tariff if the social benefits generated by the implementation of such pricing regimes are higher than the social benefits brought about by the implementation of the incentive pricing schemes:

$$z = \max\{z_{FR}; z_{IT}\} \qquad (5.11)$$

Where, z_{FR} and z_{IT} stand respectively for the social benefit under the flat rate pricing scenario and the social benefit under the incentive pricing scenario. For the flat rate scenario, transaction costs are assumed to equal zero.

As stated previously, the prerequisite to implement an incentive tariff is that the probability to detect farmers as compliant when they are actually complying must dominate the probability to detect farmers as compliant when they are actually not complying. Such a prerequisite of dominance is a necessary condition to implement an incentive tariff, but is not a sufficient condition to justify the transition from the flat rate regime to the incentive pricing regime. The transition is favoured for high levels of supply costs recovered by pricing water, for high degrees of accuracy of the instruments adopted by the WA to monitor water usage and for low levels of transaction costs faced by the WA with the implementation of the incentive pricing scheme.

Another aspect motivating the transition from the flat rate regime to the incentive pricing regime is the presence of a heterogeneous population of farmers. Unlike the flat rate, incentive pricing enables the WA to allocate supply costs among users on the basis of actual uses. This effect might positively impact overall social benefits and make it possible to tie supply costs to the benefits generated by the provision of water to irrigation.

5.3 Empirical example

5.3.1 Case study and model parameterisation

In order to assess the introduced pricing mechanisms I discuss the results obtained from Çukas, a region of Albania where the irrigation network is served by open canals. This area of Albania was selected because it comprises the most intensively irrigated agricultural area in the country and because of the need for water pricing reforms in such a regions and a country as a whole that have recently experienced stronger institutional change and major regulatory instability. Albania is blessed with plentiful water resources, but due to the lack of maintenance and poor management of irrigation infrastructure, and lack of an appropriate monitoring system, the needs for irrigation are currently not met in time and quantity. As a result, the efficiency of water use for agriculture remains low. In this context, the main concern is the compliance with EU legislation and the WFD implementations.

The cultivated area is approximately 5630 ha out of which 4405 ha are cultivated. The main crops are: winter wheat, maize, alfalfa, vegetables, beans, greenhouse vegetables, and grapes. The average farm size is quite small (1.4 ha) compared with the average of EU countries and farms comprise mixed cultivated crops with diverse water requirements that are served from open canals. In the past (before 2016) water management was under Water User Associations (WUAs) and the establishment of WUAs was in accordance with Law No. 9860 of 2008, later amended and supplemented by Law No. 8518 of 1999 regulating irrigation and drainage. In 2017 the management decisions were delegated to the municipalities. Nonetheless, the municipalities can also delegate the management and tariff collections to the WUA.

Tariff setting is now carried out according to the new Law No. 24/2017 for the administration of irrigation and drainage whereas Article 20 regulates water tariffs for supplying the water to farmers. The municipality sets a tariff level for each farmer based on farmers' irrigation water requests. For surface irrigation networks, the water tariffs are estimated based on the irrigated area and disregarding the irrigated crop. The water tariffs include all water supply costs to deliver water to the farm and are approved by the municipality council. Tariffs are set under a flat rate system with the sole purpose of recovering water supply costs. The tariff is hence uncorrelated to the amount of water consumed. The WA estimates only the irrigated hectares and disregards the cultivated crops in the area. The water tariffs are usually determined *ex ante* by allowing the regulator to estimate the overall irrigated area as farmers pay and sign for irrigated hectare. There are usually cases where a farmer has not paid in advance but irrigates during the irrigation season (Lika et al., 2016). Accordingly, recovery of supply costs do not reach the expected level. In addition, the WA, based on Legislation No. 24/2017 for the administration of irrigation and drainage, has no clear strategy of monitoring water users; the regulator only monitors and provides evidence for the overall amount of water used during the entire year.

In addition, as Albania's intention is to join the EU, water policies must conform to the EU's legislation and strategies. In line with the EU's strategies, there is a need for determining new water pricing policies that ensure the sustainability and the efficiency of water use.

In this regard is developed incentive water pricing strategy under monitoring conditions because of its potential implementation in the region, and, possibly, in other irrigation networks with similar characteristics. The reason for underlying pricing schemes with asymmetric information is because the irrigation region is highly characterized by information asymmetries as well the impossibility of implementing a direct volumetric pricing due to unmetered irrigation water use. Moreover, the flat rate water pricing approach implemented in the region does not provide any incentives to farmers for rational water use.

According to the mechanism introduced above, in this example it is assessed the per hectare social benefit generated in an agricultural region served by surface irrigation networks under the flat rate pricing scheme. Then, I compare the current situation with incentive pricing schemes under different assumptions with the aim of identifying the condition under which the introduction of incentive pricing schemes might be viable.

To introduce this illustrative case, the profit and cost function are obtained from (Lika et al., 2016). In this application are assumed two levels of water supply costs. First, water supply costs are the same as in the reference case (0.06 €/m3). Then, water supply costs are assumed to increase ten times with respect to the reference value (0.6 €/m3). This scenario is introduced with the twofold purpose of emphasizing the possible effects generated by the implementation of incentive pricing schemes and to include other potential costs not actually accounted for WAs in Albania, such as the environmental costs caused by the decay of the status of water resources as a result of irrigation.

The farm's profit functions is estimated based on the difference of the profit obtained for each irrigated crop and the profit obtained for non irrigated crops with respect to the share of irrigated area. A quadratic concave profit function is used $\pi(x)$ for a given farm type. The farm's profit function is calculated as a farm's revenue from cultivation minus expenses for seed or plants, fertilizer, pesticides, and tilling, while costs such as labour are not subtracted. The water supply costs $c(x)$ are determined based on crop water consumption and unit water cost with respect to each farm type; in this way is estimated the cost of water for each crop, which allows for determining the total water supply cost for overall irrigated area with regard to the type. The estimated water supply costs include payment to water masters to clean and maintain the secondary canals, as well as the management and distribution of water to tertiary canals to facilitate withdrawal by farmers (Lika et al., 2016).

5.3.2 Results

The assessment of two water pricing policies is illustrated by Figure 5.1-5.6.

Figure 5.1 and 5.2 illustrates how the level of sanction varies with probability of detection and transaction costs (i.e. in figures, for the simplicity of representing the effects of probabilities, the variation of P_0 and P_1 are considered as increasing or decreasing with the same scale). The solution accounts for different levels of monitoring probability and transaction costs. The monitoring costs are assumed to be a parameter in the objective function, which do not influence in the analytical way the solution of the problem, but would effect in the efficiency of incentive water pricing scheme.

Figure 5.1 shows that the value of sanction start increasing only above some threshold of probability of detection and reaches its highest level then start decreasing. With increasing probability of being detected, above the threshold level, farms costly behaviour decreases because of high possibility of being caught. When probability of detection goes toward maximum, the farmer irrigate optimally as in the full information condition. This implies that from equation (5.10) the value of sanction still is positive even the monitoring probability goes toward 1 and this happened due do the positive difference of nominators (irrigated share) in equation (5.10). Furthermore, when the necessary condition set above is violated (i.e. the rage of possible values for P_0 is $(1 - P_0) < P_0 < 1$ and for $(1 - P_1)$, $0 < (1 - P_1) < P_0$), monitoring probability does not impact on sanctions.

In addition, sanction is positively correlated with transaction costs as illustrated in Figure 5.2. With increasing transaction costs, sanction increases. This result happened because, high level of transaction costs effect by increasing the overall supply costs of the provision of the resource, eventually translated higher tariffs for farmers. For higher tariffs farms incentive to cheat increases because the gain by cheating, avoiding true tariffs, will be higher than the loss if being detected, in this reasoning, to avoid this costly event there is an increase of sanction up to level that dis-incentivise farms costly action.

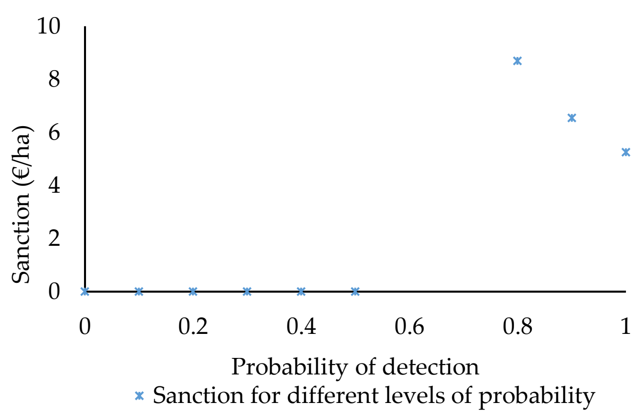

Figure 5.1. Sanctions in function of detection probabilities

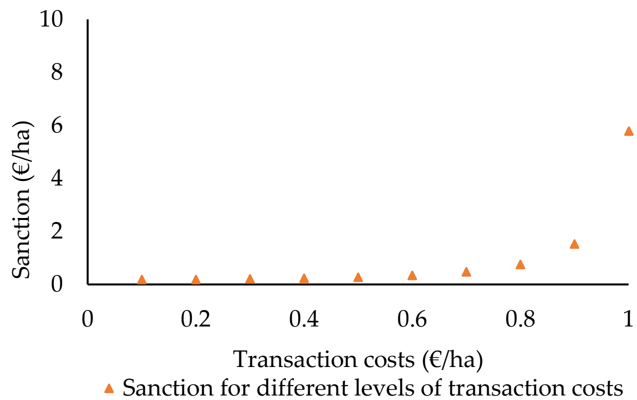

Figure 5.2. Sanctions in function of transaction costs

Figure 5.3 illustrates the variation of the share of irrigated area under two water pricing scenarios and different levels of water supply costs and transaction costs. With flat rate water pricing, the probability of detecting farms' action do not influence farms' irrigated share as farmers are not constrained in terms of water use. Under incentive tariffs, in Figure 5.3 when water supply costs are taken low (0.06 €/m3) and transaction costs high (0.5 €/ha) it is observed that above threshold level, set by the prerequisite condition, with increasing detection probabilities farmers start decreasing the irrigated share. Comparing this result with Figure 5.4 in which water supply costs are taken high (0.6 €/m3) and transaction costs are low (0.005 €/ha) the effect of the probability of detection on the irrigated share is the same but for higher water supply costs, at some interval of probabilities of detection, farmer trend to decrease the irrigated share in a larger size. This outcome is achieved because of high water supply costs. If the farmer continues to keep a higher irrigated share his net profit decreases and he will not be better off. In addition, in Figure 5.4 above the threshold level of monitoring probabilities the blue line becomes flat. This effect occurs because of sanction effect. For higher water costs, its effect on the farm's net profit becomes stronger and the farmer prefers compliance instead increasing the irrigated share with the possibility of being sanctioned.

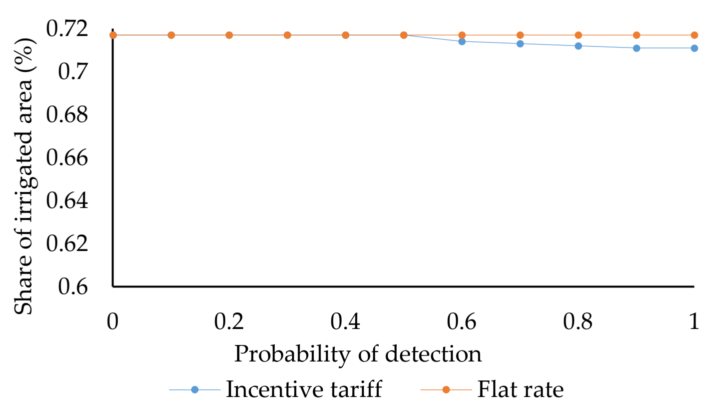

Figure 5.3. The variation of irrigated share for water cost at 0.06 €/m3 and transaction costs 0.5 €/ha

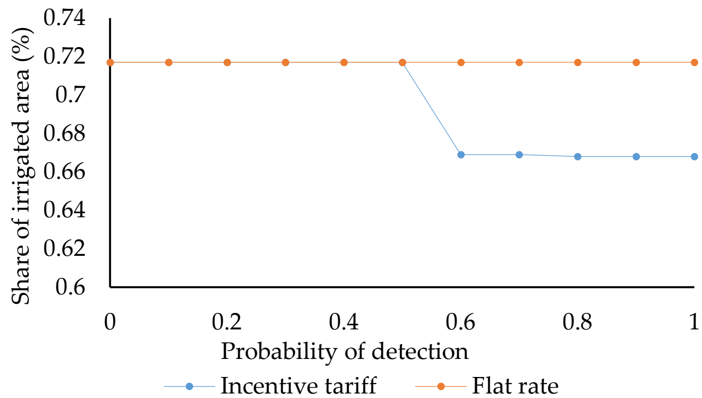

Figure 5.4. The variation of irrigated share for water cost at 0.6 €/m3 and transaction costs 0.005 €/ha

Figure 5.5 shows the variation of social benefit under incentive tariffs and flat rates. The observed level of social benefits is achieved under water supply costs and transaction costs as in Figure 5.3. The share of irrigated area for water cost 0.06 €/m3 and transaction costs 0.5 €/ha and the presence of transaction costs are assumed only under incentive water pricing.

Figure 5.5 shows that for low water supply costs and high transaction costs the incentive water pricing strategy is not preferred by the WA because the social benefits under this pricing instrument are lower than in flat rates, even the detection probabilities are increasing. Under this situation, transaction costs decrease the expected social benefits and the WA would impose a flat rate strategy. The numerical example also proves that the curve of social benefit seems to be flat for both pricing strategies. Under a flat rate the line is flat because probabilities have no effect on irrigated shares and tariffs, and eventually do not effect social benefits. Despite the high level of probability of detection, under incentive tariffs for low water costs, farmer decreases the irrigated share in a small size (in decimals),which have little effect on sanction and only a very small effect on the social benefit. In addition, from the observed outcome of social benefits, for higher levels of transaction costs the implementation of incentive tariffs is not justified.

The comparability of two pricing instruments becomes more evident when the water supply costs are higher and transaction costs are low as illustrated in Figure 5.6. This example considers the water supply costs that are similar to those of European countries where the unitary cost of water is higher compared to reference cases (Giannakis et al., 2016)

For flat rate water pricing the same effect is observed as in Figure 5.5. For incentive water tariffs, the social benefit varies with the level of probability of detection. Below the threshold level of monitoring probabilities, the WA face water supply costs and transaction costs that achieve lower levels of social benefits compared with the flat rate. When the monitoring probability exceeds the threshold level its impact on improving social benefits becomes evident. As the probability of detecting a farm’s action increases, the social benefit increases and under a certain level of monitoring probability the social benefit with regard to incentive tariffs becomes much greater than in the flat rate case. The efficacy of incentive water tariffs increases and results in greater social benefits.

Notably from Figure 5.6 the variation of the social benefit is not too high, even when transaction are high. This is explained with the fact that, the effect of transaction costs on the overall water supply costs is not so strong so as to push farmers toward a higher decrease of irrigated share. The cultivated crop of chosen farm type hare high productive crop, which means until some level of water tariff the demand for water is inelastic. If tariffs do not influence to much in water demand farmer will not decreasing the irrigated share in high portion. As the irrigated share is a decision variable and influences farms profit and social benefits, this implies that the effect on social benefit will be small and this explains the fact why the variation of the social benefit is not to large even with high level of transaction costs.

In addition, the numerical example shows that when the level of water costs and transaction costs are preclusive, the efficacy of incentive mechanisms is limited. The numerical example illustrates that only above a certain threshold level of monitoring probabilities (with respect to water supply costs and transaction costs) the incentive tariffs perform better than the flat rate in terms of social benefits.

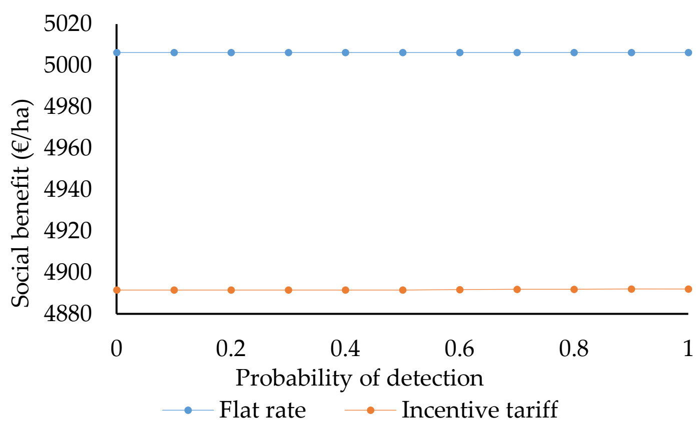

Figure 5.5. Social benefit under two pricing options for water cost at 0.06 €/m3 and transaction costs at 0.5 €/ha

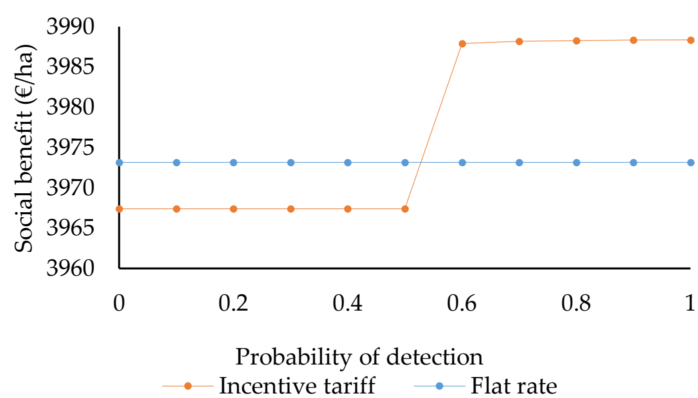

Figure 5.6. Social benefit under two pricing options for water cost at 0.6 €/m3 and transaction costs at 0.005 €/ha

5.4 Discussion and conclusions

The paper analyses a model of a non-linear water pricing scheme and examines the implications of moral hazard problems while designing water pricing strategies for irrigated agriculture. The focus of the paper was to develop an incentive water pricing instrument that would influence farm behaviour towards a more efficient use of water. The model is designed as a social welfare maximizing problem that includes the maximization of farm benefits and costs to regulators.

In recent decades, many scholars have analysed the problem of moral hazard in agriculture by using principal-agent theory (Hart and Latacz-Lohmann, 2005; Choe and Fraser, 1988; Ozanne et al., 2001; Millock et al., 2012; Fraser. 2002, 2013). The authors have given attention to developing models in order to overcome the problem of moral hazard in agri-environmental policies. With regard to irrigated agriculture Smith ant Tsur, (1997) provide a pricing strategy by applying a revelation mechanism with a focus on analysing the implications of adverse selection and moral hazard.

With regard to the above-reference literature, to my knowledge, the model has not yet been applied in an empirically tractable form in the field of irrigated agriculture. The model seeks to provide a pricing scheme through a monitoring strategy that would dis-incentivize farms from cheating and guarantee a higher benefit when complying with agreement entered into with WAs. The implementation of incentive water tariffs results from the need to share supply costs among users according to water use and dis-incentivizing farmers from water misuse, in contrast with the flat rate where farmers benefit from payments that are set equally among farmers. The use of flat rate water pricing in irrigation regions is justified because it is easier to implement despite the fact that this instrument allows for significant water wastage and large economic costs. Moreover, current tariffs do not reflect the true cost of water, as tariffs are used to recover maintenance costs and not capital and environmental costs. As a result, tariffs are low and any variation in the pricing criteria would not contribute to generating appreciable benefits, especially considering the low elasticity characterizing the demand for irrigation water.

The application of the PPP might cause increases in the tariff level due to the need to recover the environmental costs generated by upstream pressures on water resources caused by agricultural activities. Downstream pressures on water resources from agricultural activities (i.e. nutrient leaching), could be tackled through the application of additional instruments (i.e. imposition of restrictions on fertilizer use and/or higher fertilizer prices). In any case, the application of the PPP determines higher tariffs. Consequently, with flat rates the disparity would increase among farmers using more water than they pay for and farmers using less water than they pay for. The application of the IPP makes it possible to solve this discrepancy, and also contributes to reducing pressures on water resources.

By referring to introduced methodological approach, the application of the PPP might result in an increase in the tariff level for both the flat rate and the incentive tariff scenarios. Any increase in the tariff level goes hand in hand with an increase in the benefits obtained with the transition to incentive pricing schemes. However, the application of the PPP, in addition to the IPP, could contribute to the generation of higher transaction costs (also in the form of information rents) which could, in turn, offset the additional benefits brought about by tariff improvements. The net balance is a numerical issue depending on the individual case.

Our results indicate that when the water supply costs are low and transaction costs are high incentive water pricing is less preferable than flat rate pricing. The efficacy of the incentive water pricing strategy increases with increasing water supply costs and decreasing transaction costs. In addition, the monitoring strategy, to be effective, requires that the probability of detecting the actions of the farmer be high in order to maximize social benefits. On the other hand, if the WA establishes low monitoring measures there is benefit loss as farmers may undertake costly actions. With regard to the case study, if the water supply costs are too low and transaction costs high, as assumed, the incentive tariffs do not justify their implementation in terms of social benefits because the presence of transaction costs negatively impact on the efficiency of incentive water pricing and makes it less efficient than flat rate pricing. However, this scenario should be further investigated to estimate the actual transaction costs involved in applying incentive tariffs in the region. It is worth noting that this region has the most intensive agricultural production in Albania and analysing the actual irrigation water pricing problems and suggestion of a new water pricing policies might be in its advantage for the time being or for the future. In light of the fact that water supply costs may increase, the second scenario may be applied (i.e. 0.6 €/m3) which implies that the gain in social benefits from incentive tariffs will be significantly increased.

In addition, if no other outside options exist (i.e. pricing water volumetrically or introducing other strategies that allow for sustainable irrigated agriculture) monitoring strategies should be considered as an effective measure in the irrigation projects where its characteristics make it possible to apply this instrument.

In this regard, the model can be proposed for application in other areas where irrigation networks are via open canals and water delivered to farms is unmetered (e.g. in Austria, Belgium, Spain, Italy or Greece). Furthermore, the model allows for financial sustainability. The WA at least recovers the water supply costs and imposes a strategy according to which farmers manage water resources in a manner that is consistent with water conservation efforts and discourages misleading incentives (irrigating higher irrigated share than agree *ex ante*).

The model has several limitations; the main one is that it counts for a single period. In the multi period case the water authority would have the opportunity to receive information about the farm's past behaviour as such behaviour may persist in upcoming periods and alter tariffs and irrigated shares accordingly. This would increase the efficiency of the monitoring activity and impact on the WA's revenue and the farm's benefit. This also enables the WA to improve its ability to target its verification efforts in the future (Hart and Latacz-Lohmann, 2005).

Furthermore, the provided model is based on several simplified assumptions, among which the fact that it does not account for the effects of monitoring efforts on cost and effectiveness. However, the model can be extended and developed in several ways, one of which might be to analyse a case in which monitoring costs are a function of monitoring frequency (commonly applied in agri-environmental schemes) or extending the model by introducing the problem of adverse selection which could further hinder the possibility of discriminating tariffs among farmers. This development is beyond the scope of this paper and might be an interesting topic for future research.

Chapter 6

6. Designing Water Pricing Policies under Moral Hazard: A case of Modelling Monitoring Costs in Function of Monitoring Efforts

6.1 Objective

The objective of this study is to analyse a pricing strategy under the problem of moral hazard where monitoring costs are function of monitoring efforts. In addition, with this study I aim at demonstrating under what levels monitoring is efficient and in term of policy implications I attempt to illustrate the effect of the mora hazard problem in irrigated agriculture.

This research is based on the literature that treats the asymmetric information for irrigated agriculture as Galioto et al. (2013), Ozanne et al. (2001) and the study describes the need to implement monitoring tools in irrigated agriculture systems and introduce a pricing scheme by trying to incorporate monitoring costs on the incentive water tariffs.

This chapter is organized in four sections. In section two is developed the theoretical model and start by assuming that the WA can fully detect farm's action, then the study extends to the model development by introducing a case when the WA does not have full information about farm's action and involves some probability of detecting farm's behaviour. In the third section I attempt to provide an empirical example and check under what conditions the monitoring intensity is efficient. The chapter ends by drawing some discussion and conclusions.

6.2 Theoretical model

This section sets up a theoretical model based in principal-agent theory for providing an incentive water-pricing scheme. The principal is the WA who supplies water to farmers and the agent is a farmer who demands water from the WA.

The application of principal-agent model is intended to apply some economic criteria for water management in irrigated agriculture. The model identifies under what condition is optimal for the WA to monitor farmers with the intention of mitigating costs arising by farms' cheating action. Their action consist in reduced cost-effectiveness of the policy outcome (Fraser, 2013). In addition, farmers action is assumed to be one dimensional, complying or not with the agreed rules for the irrigated share.

In this setting is considered that the WA deals with one farmer. The relationship between WA and the farmer is such that, the WA delivers and manages the water resource and the farmer irrigates the land in return for a payment in form of tariffs. The WA's objective is to maximize social benefits by making an offer to the farmer. The farmer is supposed to accept the offer but might be compliant or not.

In following the model assumes that the farmer and the WA share the same information in term of water use and its profitability than analysis extends to a moral hazard where asymmetric information occurs. Moral hazard problem enters when farmer takes some action that would result costly for the WA (e.g. during the irrigation season farmer irrigates a greater share compared with what agreed before the irrigation season) and has a twofold impact on the regulator's costs: increasing costs for supplying water into the network and increasing costs because of being obliged to implement a monitoring strategy to prevent such a farmer behaviour. In order to prevent any costly action, during the irrigation season, the WA try to incentivise the farmer to comply with what he has agreed in the past. The designed strategy is such that the WA monitor his irrigated area and cultivated crops in the way of detecting whether there are irregularities compare with what farmer declared *ex ante*. The model setting under monitoring activity would allow the farmer to participate and give him the opportunity to avoid the extra costs in form of sanction that he receives if would be found noncompliant with the rules of the contract.

The intention of the WA is to determine a water-pricing scheme that allow the farmer to pay the water tariff according to the amount of water consumed. I am aware that under surface irrigation network is not possible to measure in unites a delivered amount in the farm. To this concern, I consider farm's irrigated share as a proxy of farm's water use. This allows to link water tariffs with farm water consumption. The irrigated share is defined such that, the WA and the farmer agree before the irrigation season on cultivated crops in a given area and the WA estimates the crop water requirements and determines the total amount of water that a farm needs during the entire irrigation season. This way, based in the overall cultivated area the WA easily can determine the share of irrigated area for each farm, similar to the paper of Lika et al., 2016.

According to this assumption, is assumed that the WA proposes an offer that combines the share of irrigated area and the water tariff $\{x, t\}$. Bearing in mind that the WA wants to determine farm's irrigated share at the level of what is optimal from the social point of view x with respect to associated tariff t. Under this conditions farmer accept the contract *ex ante* but might not comply *ex post* because might choose a level of irrigated share which is optimal from private point of view x^{PR} that maximizes his profit. If the farmer chooses to irrigated x^{PR} he applies unrestricted level of water use and receives a level of profit $\pi(x^{PR})$. If the farmer choose to irrigate the share of what is optimal from social point of view he would be restricted on the share of irrigated area and receives a restricted level of profit $\pi(x)$ where $\pi(x^{PR}) \geq \pi(x)$.

Moreover, if the farmer chooses to irrigate x instead of x^{PR} he receives a disutility, defined by the difference between the profit received by irrigating from what is optimal from private point of view and from what is optimal from the social point of view.

$$\psi(x) = \pi(x^{PR}) - \pi(x) \tag{6.1}$$

If the WA is able to fully detect farm's action and finds no irregularities in the irrigation network, the farmer would pay the tariff t. Otherwise, the WA sanction the farmer σ for being noncompliant with the statement. The sanction is in the form of extra payment and its role is to dis-incentivise the farmer from cheating action. If the farmer non-complies with the rules and avoid to be caught from the WA he avoids the loss from sanction. This loss is defined by the level of utility that he receives $u(\sigma) = \sigma$[7]. The difference between the received utility and disutility determines net utility.

$$U = u(\sigma) - \psi(x) \quad (6.2)$$

6.2.1 Model under full information

Under full information the WA offers a contract to the farmer where specifies the share of irrigated area and the associated water tariff. Without loss of generality, the irrigated share is receive as a proxy of water use and equals 1. The water tariff depends on the water supply cost function. Under this setting is assumed the WA is fully able to detect farm's action and the social welfare maximizing objective function takes the following form:

$$\max Z(x,t) = \pi(x) - c(x) - \delta t \quad (6.3)$$

s.t.

$$\text{CR: } t \geq c(x) + \delta\, t \quad (6.4)$$

The objective function involves a quadratic farm's profit function $\pi(x)$ which is considered $\pi(x)' > 0$ and means that profit function is increasing at x and $\pi(x)'' \leq 0$ with a constant sign as used in most of the literature (see the text book of Salanie, 2005). The second component $c(x)$ indicates that the WA has some costs to supply water to the farm and $c(x)' > 0, c(x)'' \leq 0$. The third term indicates the value of transaction costs in function of tariff, defined by symbol δ which is a linear parameter on tariff. Transaction costs are received to be costs of implementing the pricing strategy. The cost recovery constraint (CR) indicates that the tariff pied by farmer must at least include costs generated by supplying water to the farmer and costs of implementing the pricing scheme.

Under such a situation it is assumed that CR binds with strict equality. That is, the water tariff is set exactly up to level of water supply costs plus transaction costs, because of the regulator's desire to receive from farmers the water tariff as close as possible with the real costs. By solving the equation (6.4) with equal sign is determined the value of tariff:

$$t = c(x) + \delta\, t$$

$$t = \frac{c(x)}{1-\delta} \quad (6.6)$$

Equation (6.6) means that the optimal level of tariff is in function of the irrigated share and transaction costs.

By substituting in the objective function the equation (6.6) and taking the first order condition (FCO) with respect to x the solution yields:

$$\pi'(x^*) = \frac{c\prime(x^*)}{(1-\delta)} \quad (6.7)$$

[7] This item can be considered as an opportunity costs of compliance

From solution of equation (6.7) is determined the optimal level of irrigated share x^* from WA's point of view that is weighted by transaction costs (full derivation of results is given in appendix 6.2.1). Substitution this value in the equation (6.6) the value of tariff can be determined. As the derivative is $\pi'(x^*) \neq c'(x^*), \forall\, \delta\ \neq 0$ this result tells us that water tariffs are set at different level from $'(x^*) = c'(x^*)$. The difference is subject of the value of the transaction cost.

6.2.2 Model under moral hazard

Let's consider the case when the WA's monitoring accuracy is not fully efficient but the WA has some probability of detecting farm's noncompliance. The level of the social benefit at this instance is also influenced by farm's action chosen to comply with the statement, the probability of detection if the farmer non comply and the level of sanction imposed to the farmer.

Let $P(m)$ be the probability of detecting the noncompliant farmer depending on monitoring intensity m and assumed $P'(m) > 0$, $P''(m) = 0$. Monitoring is costly for the WA, this is indicated by the item k linear on monitoring intensity m.

Under this setting is considered that the farmer participate in the scheme but can pursue a strategy of complying with rules or noncomplying. Thus, farm's participation is ensured but its compliance remains contingent of farm's choice. Given that the farmer is fully informed about the outcome achieved from his action, by participation he makes a net profit corresponding to the level of the difference of the profit achieved by the restricted level of irrigated share with the tariff $(x) = \pi(x) -\ t$. If the farmer decide to take action of irrigating up to his private optimal irrigation share x^{PR}, his level of net profit is depended on whether or not is detected by the WA (i.e. $V(x^{PR}) = P(m)(\pi(x^{PR}) -\ t -\ \sigma) + \big(1 - P(m)\big)(\pi(x^{PR}) -\ t)$).

The readjusted objective function (6.3) takes the following from:

$$\max Z(x,t,m) =\ \pi(x) -\ c(x) - \delta(t + \sigma) - km \tag{6.8}$$

s.t.

$$\text{CR: } t \geq\ c(x) + \delta\, t + km \tag{6.9}$$

$$\text{IC: } \pi(x) - t \geq \pi(x^{PR}) -\ t - P(m)\, \sigma \tag{6.10}$$

The term km entered in the objective function (6.8) indicate that the WA in addition to the previews costs face costs of monitoring farm's action. Furthermore in the objective function is involved the transaction cost linear on tariff and sanction. The CR constraint indicate that the water tariff paid by farmer must include the cost of supplying water to him $c(x)$, transaction costs $\delta\, t$ and monitoring costs km. The incentive constraint described by equation (6.10) is a reduced form of $\pi(x) - t \geq P(m)(\pi(x^{PR}) -\ t -\ \sigma) + \big(1 - P(m)\big)(\pi(x^{PR}) -\ t)$ which indicate that compliance would secure the farmer a level of net profits higher or at least as non-compliance.

In this line the WA can deal with moral hazard problem by providing to the farmer an offer which would give him an incentive to be compliant (t, x). If the farmer complies the offer should secure him a greater level of utility instead of cheating.

In addition, it is assumed that both constraints (CR and IC) are binding in optimum. Therefore the WA's problem is:

$$Z(x,t,m) = \pi(x) - c(x) - \delta(t+\sigma) - km \tag{6.8}$$

s.t.

CR: $t = c(x) + \delta\, t + km$

IC: $\pi(x) - t = \pi(x^{PR}) - t - P(m)\,\sigma$

The maximization of social benefit from the equation (6.8) now is contingent of the optimal level or irrigated share x, the tariff t and probability of detecting the noncompliant farmer $P(m)$. From equation (6.10) the value of sanction is determined when this equation binds with strict equality (i.e. the IC binds because the value of sanction increases up to level that the constraint is binding). By solving equation (6.9) and (6.10) the outcome yield:

$$t = \frac{c(x)+km}{(1-\delta)} \tag{6.11}$$

The optimal level of tariffs now is determined from the ratio of the sum of water supply and monitoring costs with weighted value of transaction costs.

$$\sigma = \frac{\pi(x^{PR}) - \pi(x)}{P(m)} \tag{6.12}$$

The value of the sanction (6.12) is determined from the outcome of the ration of the difference of the private profit with the profit determined from the optimal level of irrigated share by WA's point of view with the probability of detecting the noncompliant farmer. Substituting equation (6.11) and (6.12) in the objective function and taking the FCO with respect to x and m, the following solution is as in equation (6.13) and (6.14). By solving equation (6.13) is determine the optimal level of irrigated share from the WA's point of view and the optimal level of monitoring probability from equation (6.14) (i.e. full derivation of this results is provided in the appendix 6.2.2).

$$\pi(x)' = \left(\frac{c(x)'}{\left(1+\frac{\delta}{P(m)}\right)(1-\delta)}\right) \tag{6.13}$$

$$P(m) = \sqrt{\frac{k}{\left(\pi(x^{PR})-\pi(x)\right)(1-\delta)P(m)'}} \tag{6.14}$$

The solution of equation (6.13) has several implications. If the $P(m) = 1$ indicate that monitoring intensity is maximized and the WA can perfectly detect farm's action. In addition the value of x determined from equation (6.13) (if $P(m) = 1$) is contingent of transaction costs. Moreover, transaction costs would affect the value of sanction estimated from equation (6.12).

If the WA reduces the monitoring intensity there is a decrease of probability of detecting the noncompliant farmer. The decrease of $P(m)$ (i.e. with respect to constant level of transaction costs) impact on the increase of the ration of the denominator in equation (6.13) leading to an increase of irrigated share toward the x^{PR}. For increasing farm's irrigated share there is a twofold outcome from equation (6.12): the difference of the nominator will be decreased but the general outcome of the sanction increases due to the $P(m)$ decreases. Additional increase of sanction would further disincentives the farmer to take a cheating action.

In addition, the optimal level of monitoring probability determined in equation (6.14) depends from the level of monitoring costs k which is in function of monitoring intensity, farm's profit for a given irrigated share and transaction costs.

To this end the main result is that the WA has a trade-off between the loos from the costs arriving from supplying water for higher irrigation share compare with what is optimal from his point of view and the gain from maintaining low level of monitoring costs by decreasing monitoring intensity ($m < m^{max}$) where m^{max} indicate the maximum level of monitoring intensity.

6.3 Numerical Example

In this section, I illustrate the moral hazard model based on an empirical simulation and assess farm's behaviour in function of monitoring intensity set by the WA. For the purpose of this simulation example a quadratic profit and cost functions[8] are assumed $y = -ax^2 + bx$ and linear monitoring cost function k depending on the monitoring intensity km.

Simulation results illustrate the assumption about the variation of monitoring intensity and two stage level of transaction costs. The result of this hypothesis are provided in the table 6.1.
The main result of this analysis is that the WA is willing to set monitoring intensity considerably less than the maximal possible level. Only when transaction costs increase and monitoring cost are constant is found that the WA increases monitoring intensity. This result occurs because when the gain by maintaining compliance far exceeds the possible costs from monitoring the desired WA's monitoring intensity remains high.

In both scenarios with decreasing monitoring intensity the irrigated share increases and eventually tariffs increase. The increase of farm's irrigated share is in line with the reasoning that at some level of probability of detection the gain from irrigation exceeds the possible extra payment received by sanction. In addition, for $m > 0$ farm's irrigated share remains below the level of unrestricted farm's irrigates share that is the farm's profit maximizing irrigable land use. Nevertheless, by keeping non-profit maximizing irrigated share the associated water tariffs are lower compare with what would be under unrestricted irrigated share.

Moreover, the increase of monitoring intensity would negatively influence sanction being decreasing as the monitoring intensity increases. This observation is in accordance with the equation (6.12). As expected, another inference is that the decrease of sanction leads to a lower level of transaction costs, arising by sanction, on the other hand puts monitoring costs under

[8] The profit and costs function are taken from the paper of Gallerani, (2005) and are further adjusted for testing the functionality of the model. The estimation of cost function is made based in farms water requirement with regard to cultivated crop and water supply costs is assumed 0.6 €/m3 much higher than the reference case. In addition the monitoring costs function is hypothetically created.

pressure. As it turns out, WA's trade-off is between maintaining low level of transaction costs arising by sanction with the costs arising by monitoring intensity.

It is interesting to note also that increasing transaction costs leads to an overall decrease of irrigated share, but compared with the previews level of transaction costs (0.05 €/ha) it is realised that the farmer for low level of monitoring intensity increase the irrigated share in a larger size. This result happened because the increase of transaction costs means that farmers are irrigating at higher water cost level which eventually raise their willingness to take a costly action. In this manner the WA is forced to raise the level of monitoring intensity to prevent such a behaviour as provided in the second part of the table by numbers in bold which represent the level of social benefits.

On the other hand higher monitoring intensity are translated in higher monitoring costs, hence high monitoring costs might not be justified by the gain of inducing farm's compliance. In this respect the maximization of social benefit is achieved at lower level than the maximum level of monitoring intensity.

Table 6.1. Monitoring intensity, transaction costs, irrigated share, water tariffs, sanction, monitoring costs, farm's profit with restriction on water use and with no restriction in water use, social benefit.

m	δ	x	t	σ	km	$\pi(x)$	$\pi(x^{PR})$	z
1	0.05	0.668	1169.2	23.54	5	5097.54	5121.07	3927.16
0.9	0.05	0.668	1168.96	25.85	4.5	5097.81	5121.07	3927.56
0.8	0.05	0.668	1168.79	28.66	4	5098.15	5121.07	3927.92
0.7	0.05	0.669	1168.72	32.14	3.5	5098.57	5121.07	3928.25
0.6	0.05	0.67	1168.78	36.59	3	5099.12	5121.07	3928.51
0.5	0.05	0.672	1169.05	42.45	2.5	5099.85	5121.07	3928.67
0.4	0.05	0.672	1169.67	50.48	2	5100.88	5121.07	**3928.68**
0.3	0.05	0.673	1170.93	62.11	1.5	5102.44	5121.07	3928.4
0.2	0.05	0.677	1173.57	80.05	1	5105.06	5121.07	3927.49
0.1	0.05	0.684	1180.18	107.73	0.5	5110.3	5121.07	3924.73
0	0.05	0.717	1210.79	0	0	5121.07	5121.07	3910.28
m	δ	x	t	σ	km	$\pi(x)$	$\pi(x^{PR})$	z
1	0.1	0.668	1233.71	23.94	5	5097.14	5121.07	3861.03
0.9	0.1	0.668	1233.74	26.01	4.5	5097.67	5121.07	3861.32
0.8	0.1	0.668	1233.9	28.46	4	5098.31	5121.07	3861.56
0.7	0.1	0.669	1234.24	31.4	3.5	5099.09	5121.07	3861.71
0.6	0.1	0.671	1234.82	35	3	5100.07	5121.07	**3861.76**
0.5	0.1	0.672	1235.76	39.46	2.5	5101.34	5121.07	3861.63
0.4	0.1	0.674	1237.29	45.07	2	5103.04	5121.07	3861.25
0.3	0.1	0.677	1239.81	52.16	1.5	5105.43	5121.07	3860.4
0.2	0.1	0.682	1244.25	60.54	1	5108.96	5121.07	3858.66
0.1	0.1	0.691	1253.23	65.37	0.5	5114.54	5121.07	3854.77
0	0.1	0.717	1278.06	0	0	5121.07	5121.07	3843.01

As it turns out the main result from this table and with a policy implication consist in the fact that the WA act strategically in the way of maximizing social benefits and in inducing monitoring intensity for detecting farms action. In term of policy implication this result indicates that the WA chooses to keep low monitoring costs in order to avoid the losses on the social benefit.

6.4 Discussion and Conclusions

In this study a principal-agent model is developed by demonstrating how the WA could mitigate the negative impact of the moral hazard problem for irrigated agriculture. The model is straightforward and does not integrate complexities in term of increasing level of information asymmetries. According to the mechanism design results suggest that the WA is able to keep higher level of social benefits even when the monitoring intensity is not maximized. Nevertheless, this result varies with level of monitoring costs.

The proposed incentive water pricing scheme can be considered as an efficient mechanism for sustainability of the use of water resource and might reach the WFD objective in term of integration of economic tools.

Under full information the implementation of pricing strategy is straightforward. Under incomplete information the solution changes by weakening the efficacy of pricing strategy. Needs to be highlighted the optimal solution is deviated from the one with full information because of implications of monitoring and transaction costs. Especially transaction costs arising by sanction and cost of monitoring are fundamental in determining the new equilibrium solution under incomplete information.

In addition, involving sanction in modelling approach, facilitates the operational way of the WA in determining the solution and adjustment of sanction in a way of making the contract incentive compactible enables the WA to avoid direct distortion of the irrigated share or tariffs. From the result this outcome is attainable because the estimation of the optimal level of sanction as a function of irrigated share and monitoring probability, in the equilibrium solution, its value is determined up to the level that incentive constraints binds. In addition, involving sanction in the model is by means of not only discouraging farm's cheating action but also influencing the increase of effectiveness of irrigation network by incentivizing the farmer to irrigate rationally.

The adoption of this water pricing scheme seeks to maintain at low level the burden of monitoring and transaction costs because at some point the gain by implementing the incentive water pricing scheme might not justify the loss in term of social benefits by monitoring (i.e. this outcome is not included in table displayed under results section but refers to the case when monitoring costs and transaction costs are higher than the one introduced so far). However, the introduced mechanisms allow to assess cases under what level monitoring is efficient and allows to easily assess trade-offs from positive impact of monitoring and costs suffering by monitoring.

The policy implication arising from study turn to be; the implementation of a pricing strategy depends upon environment surrounding the irrigation network. If the cost recovery of a providing resource is not the only goal of the WA, a more restrictive water pricing strategies may be suggested with the purpose of minimizing the costs of resource provision and resource conservation.

The model introduced at a given form has several limitations. The main one stands with the fact that its implementation relay in a hypothetic assumption, not allowing the achievement of results from real case study and realisation of its real implications. Another limitation of the model consist on the monitoring technology which is not defined in this study (i.e. but could generate different level of monitoring costs compare with the one introduced so fare) but monitoring is considered as one of possible options to deal with moral hazard problem for irrigated agriculture.

The research can be extended in exploring strategies to manage moral hazard problem in a settings with more than one farm type and checking for strategies to optimize the problem by facing different level of monitoring costs arriving from different farm types.

Chapter 7

7. Summary of Results, Contribution, Policy Implications and Limitations and Future Research

7.1 Summary of results

This research provides a formal analysis of water pricing for irrigated agriculture under asymmetric information. The focus is on two asymmetric information problems: adverse selection and moral hazard that do exist in the field of irrigated agriculture and heavily affect water pricing.

The study is based on principal-agent theory applied to the role of the WA in designing incentive water pricing schemes for the management of the water resource. Besides incentive strategies, flat rate tariffs also are analyzed, which are already applied in several surface irrigation networks of EU (Italy, Greece, Malta and Poland). More importance is given to the internal design of incentive water tariffs and how they contribute to provide incentives for a more efficient water use and a rational sharing of water supply costs for the provision of irrigation water, while the flat rate is use mostly as a benchmark solution.

The research highlights the use of incentive water pricing as a tool for improving the efficiency of irrigation networks. In general the results show that there is a possibility to achieve a more cost-effective pricing strategies than flat rates. The incentive strategies improve the outcome of the society as a whole and accomplishes at least part of the WFD principles.

What arises from the analysis is that the outcome of the policy is influenced by several factors that significantly affect the optimal solution, the chosen mechanism by the WA and also the economic efficiency of the incentive strategy. In extreme cases, economic efficiency would even suggest the WA to not adopt the incentive strategy. Anyway, it is shown that the two pricing policies have different impacts on economic and environmental indicators. In this regard in Table 7.1 some findings of each pricing instrument are summarized.

Table 7.1. Summary of results

	Pricing strategies	
	Incentive pricing	**Flat rate**
Advantages	• Water tariffs are function of farms water supply costs (i.e. tariffs are set based on individuals generated costs from irrigation) • Encourages water conservation and pollution reduction • Tariff discrimination among farmers • Monitoring tools motivate farmers toward compliance with the rules of the contract (i.e. dis-incentivise costly action) and the efficiency of monitoring strategy increases with increasing monitoring probability (i.e. in cases when monitoring costs are independent of the monitoring frequency) • The efficiency of incentive tariffs increases when water supply costs are high and transaction costs low • The society is better off with incentive strategies than flat rates (i.e. greater efficiency than flat rates)	• Farms profit is higher than incentive tariffs • Flat rates have low transaction and implementation costs • Easy to administer
Disadvantages	• Increase of water tariffs is associated with a decrease of irrigated share and decrease of farms profit • Under asymmetric information the policy needs to impose a restrictive criteria (not always) to some farmer to guarantee the implementation of the policy (i.e. the WA adjust water tariffs or irrigated share to some farmer to avoid cheating behaviour of some others) • The characteristic of farm types surrounding the irrigation region (i.e. profit and costs function, and heterogeneity in water use and irrigated share among types) not always favour the implementation of incentive tariffs • Transaction costs (i.e. direct transaction costs and indirect transaction cost) impedes implementation of incentive strategies (i.e. pushing to less efficient optimal solution) • Its implementation is more politically complicated	• Economically not efficient for resource provision • no link between water tariffs and water use • not encourages efficient water use and conservation • High environmental costs (i.e. pollution due to irrigation)

7.2 Contribution and future impact analysis

The goal of incentive water pricing is to encourage farmers to a more efficient water use. By linking water tariffs with water usage, it provides an incentive to use the water resource efficiently. In addition, it brings the message that water is a scarce resource and its availability partially depends on irrigation choices.

The European WFD, inter alia, is addressing the need of limiting the overexploitation and misuse of water resources outlining the principles upon which Member State should rearrange the governance of water resources (European Commission, 2000 and Exposito and Berbel, 2017). These are: the Full Cost Recovery (FCR) principle, addressing the need for a greater financial autonomy of local WAs; the Incentive Pricing Principle (IPP) addressing the need to use efficient economic instruments; and the Polluter Pays Principle (PPP), addressing the need to let users bear the costs they generate. However, the adaptation of these principles is challenging for most of the surface irrigation networks.

The development of incentive water pricing might be considered as a potentially cost-effective measure for the achievement of WFD objective, as the contribution of the study to the literature goes in accordance with the article 9 of Water Framework Directive 2000/60/EC. Here, the treatment of IPP is accomplished by introducing an incentive water-pricing scheme, which is designed in such a way that water tariffs paid by farmers reflect (with some approximation) the amount of water they use. The FCR implies that the amount of money collected is based on water supply costs. In principle, cost recovery here includes costs of delivering water to the farmers and in addition, it covers associated transaction costs. With regard to the PPP, the model used in this study does not incorporate an additional payment as a mean of achieving PPP criteria. This would further increase the overall tariffs to be paid by farmers which in turn affect their decision for irrigation and cultivated crop. However, the implementation of incentive pricing strategies make possible to move the system in the direction of the PPP. On the one hand, incentive pricing has an impact on water conservation and eventually resulting in water saving and nutrient leaching reduction. On the other hand, the same scheme can incorporate environmental costs as part of the cost for water provision and hence enter in the model above through the WA objective function.

On the contrary, the flat rate system of water pricing is not in accordance with WFD principles, the cost of water resource might be covered but this scheme fail to incentivize farmers for more efficient water use and also violating the PPP by not incentivizing farmers toward water conservation and pollution reduction due to irrigation.

In doing so, the incentive pricing model results in more efficient water management practice and generates higher social benefits. In addition, incentive mechanisms can be considered as a tool for increasing the efficiency of pricing policy and to achieve the goal of softening the burden of lack of information in relations of WAs-farmers.

This study contributes to the literature in several ways. First, the study improves the knowledge of the information asymmetry issue by identifying and analyzing barriers and constraints that cause information asymmetries. Then the use of principal-agent theory played an essential role in determining solutions that mitigated problems of information asymmetries in irrigated agriculture. In doing so from the use of incentive strategies, is expected an improvement of the economic and environmental conditions between the WA and farmers and enhance water use efficiency in irrigated agriculture.

Secondly, the incentive water pricing strategies introduced in previous chapters are innovative in the conceptualized form. The developed method, besides information asymmetry, count for interaction of transaction costs with price design strategies. Though irrigation water pricing schemes under adverse selection have been introduced before, most of these models do not capture the effects of transaction costs (e.g. Dridi and Khanna, 2005) or transaction costs are only considered from payment transfer as in the papers of Smith and Tsur (1997), Gallerani (2005) and Arguendas and van Soest (2011).

Smith and Tsur (1997), analyzed the incentive pricing strategy based on the observed output and considered transaction costs in function of money transfer (taxes). Their result indicate that transaction costs increase per-unit water supply costs and also decrease the slope of output schedule as transaction costs increase. These results are alike to estimates achieved in chapter three. Gallerani (2005) provides a pricing strategy under asymmetric information by incorporating transaction costs on tariffs. The way of modeling transaction costs is similar to the mechanism designed in this thesis but the author try to capture only the effects of transaction costs coming from payments. In this thesis, transaction costs are related to the implementation of the new incentive pricing criteria and to monitor water usage. The author found that transaction costs have no effect when the full costs of water use is very low, while their impact becomes evident when water costs increase. This result achieved by Gallerani, (2005) is comparable with the result achieved in this study for the fact that in both policy designs it is highlighted the negative impact on policy due to transaction costs and this becomes more evident as water costs increase. The similarity of results arise because in Gallerani (2005) and in this research transaction costs are internalized in the farm’s payment transfer (i.e. chapter 3). This directly affects their net profit and irrigated share. Eventually the negative effect of transaction costs becomes stronger as water supply costs increase.

In addition, the method used to analyze the adverse selection problem (i.e. Chapter 3) resembles the model developed by Arguendas and van Soest (2011). However, these authors analyze a strategy for provision of conservation programs and treat the role of fixed costs in achieving the optimal solution, overlooking the effects of direct transaction costs. The authors found that the optimal menu of contracts is the second best (similar with what we found in chapter 4). In comparison with this study, in Chapter 3 of the thesis is analyzed a case when the first best menu of contract is achievable even under asymmetric information. In addition, the analysis of this research highlights the importance of characteristics of profit and cost functions in driving the optimal solution and in determining the best policy option.

With regard to the moral hazard problem, few papers handle this issue. For example, Ozanne et al. (2001) addresses the moral hazard problem with the focus on the compliance monitoring on the agri-environmental schemes. The authors show that if monitoring costs are fixed, the first best level of input used and compensation payment is achievable and if monitoring costs are assumed to be a function of monitoring efforts, only the second best solution is achieved corresponding to a lower level of input abatement and payment. These results are similar to what is achieved in Chapter 5 of the thesis where the moral hazard problem is solved with no information rent and in Chapter 6 when the monitoring costs are a function of monitoring effort, resulting in a higher level of water tariffs and higher level of irrigated share. This happened because in Chapter 6 is shown that the trade-off is between low monitoring costs and the loss from costs arising from the increase of irrigated share. This is in contrary to Ozanne et al. (2001) where the trade-off is between greater input abatement and higher monitoring costs.

Furthermore, White (2002), provides a theoretical analysis of the design of menu of contracts under hidden information and hidden action. The author conclude that an input change policy can be readily modified in order to provide incentives for producers to truthful report the input use. This general conclusion is found also in the mechanism designed in this thesis because it is illustrated that distortion of tariffs or irrigated share incentivize farmers to behave truthfully.

To my knowledge, none has introduced a model that involves monitoring strategies through incentive tariffs as provided in chapter 5-6. With these models, the intention was to distinguish the problem between the WA and farmers by analyzing how the quality of information might condition the WA pricing strategies providing a motivation to use/not use flat rates in the absence of water metering. Even where these models do not show significant advantages in policy change, this background permits for further exploration of how *ex-ante* and *ex-post* analyses contribute to determine water tariffs and allocation of water resources under conditions of asymmetric information.

In addition, the method developed in this thesis allows WAs/consultants to better design pricing strategies that guarantee cost recovery when water is unmetered. The theoretical interpretation and practical examples developed so far integrate strategies that might be considered as a foundation upon which to develop policy design prescriptions for other situations, to enhance or extend other models needed to address particular research questions.

7.3 Policy implications

This research can be considered as a way of exploring possible strategies to evaluate the regulation of the water resource for irrigated agriculture by assessing some of the current policy problems and suggesting policy instruments possibly usable to meet these problems in EU regions.

In this line and based on the analysis conducted in this study the following policy implications are drawn with regard to water pricing policies:

- Policy needs to adapt to differentiated local conditions

A general lesson learned from the design of different incentive mechanisms is that policies need to adapt to different local conditions. This is especially true when information asymmetries impose costs to reveal farm water use; these different conditions, especially costs and profits from irrigation (opportunity costs or diversion and distribution costs) affects also the optimal design of policy mechanisms.

- Heterogeneity among farm types potentially affects the decision of implementation of a given policy.

The degree of farm heterogeneity in water use and land use is an important issue while designing water pricing schemes for irrigated agriculture. Indeed heterogeneity among farm types may allow WAs to implement easily discrimination policies when heterogeneity is easily observable. On the other hand, it may require high cost of implementation of a given policy design and costs of monitoring farmers can be considerable high by hindering the implementation of contract discrimination when there is a high level of heterogeneity, even if heterogeneity is known, but the characteristics of each farm are not evident.

- Policy design needs to take into account explicitly monitoring costs and information rents.

The necessity of this distinction is because transaction costs in irrigated agriculture pricing strategies are considered in the context of adaptation of a policy and are explicitly involved in a policy. Information rents are related with the distortion of the size of input or charges where there is incomplete information and come out from designing the policy, implicitly involved in the policy design. The existence of these costs affect the design of the policy instrument by making its adaptation more costly because of payment transfer, monitoring administration or costs for enforcement activities (explicit) and including information rents (implicit) by input or output distortion until making questionable the implementation of a given policy because of moving to a more costly allocation mechanisms.

- The impact of asymmetric information must be considered while designing policies.

The presence of asymmetric information problems in irrigated agriculture characterized by adverse selection and moral hazard partially explains why WAs face higher water supply costs compared with what would appear from farmers apparent use. In addition, incomplete information is fundamental in a policy design and must be taken into consideration in design and implementation processes. Often policy implementation process may require additional costs in order to reveal the lack of information. In this contest, incentive strategies might be considered as instruments which could soften the burden of information failure, having in mind that this anyway implies trade-offs or at least cost for the WA.

- Evaluation of adaptation of theoretical ideas to practice.

In theory, menu of contracts might appear more complex than what would potentially be observed in practice. In practice, relaxation of contract differentiation might be less limited compared with theoretical conceptualisation. Differentiated contracts can be established in cases where heterogeneity among farm types justify their use and implementation cost are low. The degree of differentiation does not need to be as sophisticated as theoretical analysis would hint at, but could approximate the same idea with a lower number of contracts solutions. Experiments could also be devised to check in practice the relevance of differentiation concepts. Empirical examples also show that in some cases differences among more and less sophisticated instruments are not very important, so there could be the case for keeping the status quo.

- Considering irrigated share as a proxy of volume used in policy design.

Despite the fact that water supply for irrigation is not directly measured in volumes, if available information exist about the observed variables (i.e. farm types and crop cultivated and irrigated area), the irrigated share of land could be considered as a reasonable proxy of volumes used. In some cases, in which strict volumetric pricing is not feasible, this could be considered as a good proxy for water tariffs as long as it is much better observable; when observation and detection is costly effective.

- Adaptation of monitoring tools should be given more importance in irrigated agriculture.

Adaptation of monitoring technologies is very useful to control water delivery and understating irrigation water management. In cases where illegal water usages are found, the improvement of monitoring and controlling technology may soften the burden of the social loss due to lack of information. In circumstances where there are solutions to reduce costs of monitoring, through technological improvements, this instrument must be considered. For example, satellite monitoring by using remote IT infrastructure should be seen as a part of effective option that can be used because might result cost effective to control the operation of irrigation projects. Lowering monitoring costs, has proven to have a relevance in more effective pricing design and makes more efficient to go in the direction of incentive tariffs.

- Trade-offs between incentive pricing and efficiency gain.

Incentive strategies might not always be applied because its solution might result too complicated and its efficiency gain might not justify its implementation. The complication might arise from practical issues (costs of implementation and information) or related with the political sensitivities where regulator regimes might not support the adaptation of a given policy.

- Development of policy design that guarantee cost recovery and allocative efficiency.

The irrigation water agencies that administer the water pricing system are key players to understanding the design of irrigation water tariffs and its adoption. Water agencies must consider the incentive strategies as an integral part of their structure of management plans and establishing irrigation water pricing schemes that enhance irrigation water management by adopting pricing policies that would cover the water supply cost and guarantee efficient water allocation to farmers. The results show the interplay between cost recovery and allocative efficiency and the need for joint design.

Fostering the implementation of incentive strategies would be of interest of WAs for their possible adaptation to facilitate future economic policy analysis of important yet intractable for irrigated agriculture problems. However, an effective water pricing scheme would require an *ex-ante* evaluation of potential effects on society.

With regarding to water pricing, the improvement of irrigation water systems firstly must consider the reasons behind the current pricing strategies. In this way factors that influence efficient/inefficient pricing mechanism with regard to the sector may be determined. Based on this, alternative pricing mechanisms can be better analyzed and their impact on society assessed. Therefore, water pricing strategies should be designed in function of local or particular regions with regard to irrigation systems, water availability, farm type and size, cultivated crop, irrigation technology and degree of heterogeneity.

Often well-developed theoretical strategies are not rationally established in practice. For example: if farm's action towards the water resource is not investigated by WA's, they might largely benefit by overusing the resource. Its incentive to overuse the resource arise from the information advantage that users possess. Under such a costly action, the WA must identify and clarify farms incentives toward the water resources. Once the incentives are clarified, the policy maker can analyze a situation and predict likely behavior in terms of choice of strategy and consequences that are likely to result.

7.4 Limitations and further research

The results of this thesis show that the use of incentive water tariffs with suitable contract solutions makes it possible to address to some extent the problem of information asymmetries in the irrigation sector. Water agencies may benefit from using indirect water pricing schemes that would allow modulating water tariffs with the water supply costs deriving from farmers' water use. However due to complex nature of the issue analyzed in this thesis, to carry out the analysis many assumptions have been adopted. Thereby it is important to identifying cases to which developed mechanisms are not expanded and limitations of the modeling approach.

With regard to adverse selection, one limitation might be considered that the developed model does not disentangle fixed and variable costs as applied for optimal conservation contracts on the paper of Arguedas and van Soest (2011). This extension in assessing optimal menu of contracts to a more complex environment would be another challenge for WAs in determining optimal solutions. This option would create other trade-offs between decision of suggesting a policy which might require the imposition of costly restriction on farmers or accepting deregulation.

In addition, the assessment of adverse selection problem provided contracts solution under different assumptions. However, there is still room to investigate other options considering different combination of profits and costs to check for other contract solutions (i.e. some of potential extinctions are listed in section 3.4.4). Another limitation with adverse selection problem is associated with their implementation. Indeed the mechanism designed identify several model features that have not previously introduced but its practical implement depends on the characteristics of the case study that permits to apply these strategies.

Another limitation of the study was the preclusion of estimation of well-behaved profit and costs function which limited the achievement of more tractable results. For instance the cost function estimated to provide the empirical analysis does not internalized all possible water supply costs. Which may lead to a weak performance of the model and undermining results for particular purposes. In addition, a weak assumption in the model may be considered the way that transaction costs were taken when designed the policy. For example here transaction costs are simply taken to be linear on tariffs and sanctions, but not specified in detail concerning sources and structure, which is shown to be crucial in assessing the policy implementation by the water regulator.

With regard to moral hazard, formal analyses were obtained in a simplified way by considering a single farm type, disregarding the assumption that the WA can identify a distribution of types in which practically may be difficult to realize the impact on environment and overall water supply costs. In addition, the modeling approach does not consider the presence of risk aversion. By considering a risk averse farmer, the effect of incentive tariffs would be different and likely less relevant, including another trade-off between risk distribution and ability to change farmers behavior.

The modeling approach could be further extended even without major modifications. For example defining in different manner transaction costs might result in different policy inferences. Transaction costs considered in Chapter 5 and 6 can be allocated to a specific type of transaction costs; transaction costs arising from the implementation of pricing strategy and transaction costs coming from sanctioning the farmer. Which may have the same implication in policy design, but an assessment of an empirical example in a more detailed manner can separately distinguished the impact on the society.

In addition, the research can be extended in the form of analyzing the design of mechanisms that consider moral hazard and adverse selection jointly, similar to the model designed for agri-environmental policy from White (2002). This would allow to assess the potential trade-offs between the gains achieved by implementation of the policy and the loss from costs arising from enforcement and information rents. The analysis of this problem jointly might generate other trade-off related with additional information costs needed to guarantee the provision of regulation which probably further undermines the power of incentive strategies.

Other mechanisms may be designed under the conditions of asymmetric information, checking for monitoring strategies and technologies that would result to be more socially efficient especially in cases of surface irrigation networks and investigating how the development of these mechanisms influences the WA's and farmers objective. An understanding of these concerns is relevant not only as a motivation for doing research but also for introduction of new tools and strategies for adaptation in irrigated agriculture

Another important aspect not seen here is that are not considered a combination of economic instruments (incentive water pricing) with regularity instruments (non pricing instruments). Indeed, there is an extensive literature supporting the hypothesis that enforcing incentive pricing schemes enables the reduction of pressure on water resources. In reality, tariffs are not the primary tool targeted to control water usage for irrigation (Grimble, 1999) neither to promote efficient use (Varela-Ortega et al., 1998) but is rather a way to condition the allocation of supply costs according to the alleged water use. In doing so, further development of the study may be directed toward a combination of economic and regulatory instruments (i.e. as quotas and turns play an important role in conditioning water uses, which in fact are partly approximated by this work) in designing incentive mechanisms for the management of water resources for surface irrigation networks with the main purpose to minimize the overall cost of reaching given policy objectives, as well as to generate revenues to maintain and improve water provisions, to foster water conservation and to create a permanent incentive for technological innovation.

Finally, it is important to bear in mind that irrigation water pricing options could be more adequately assessed based on improved sources and knowledge of basis information such as cost arising for supplying water to a given network, characteristics of the irrigated district in term of farm types, cultivated and irrigated area, technology and farm-level economic results.

Chapter 8

8. Conclusions

The method addressed in this study offers insights into pricing design options and a flexible criterion of assessment for identifying a tariff strategy as efficient as possible and adaptable to different conditions of asymmetric information and for different levels of water use costs and transaction costs. This research, differently from the most of the literature of water pricing under asymmetric information conditions aims at maximizing social benefits not only focusing on the cost optimization process but also considering the profit from the use of water.

The introduced incentive strategies serves as a tool for the WA to allocate water supply costs among water users based in their contribution to overall costs. In comparison with flat rate water tariffs is shown that incentive tariffs not always result in better instrument in term of maximizing social welfares. The main constraints are costs arising from asymmetric information and costs arising from direct transaction costs. When these costs are low enough, incentive water pricing are superior to a flat rate strategy and offers solution at lower social cost for provision of the water resource. On the contrary, considering cases when costs due to information asymmetry between WA and farmers are high and transaction costs are high incentive strategies turns to be costly strategy for the WA in term of maximization of social benefits. In addition, farm heterogeneity increases the benefits arising from the adoption of incentive tariffs when transaction costs are low for the provision of the resource to heterogeneous farmers.

The research concludes that when the regulator faces hidden information on distinguishing farm types, the regulator provide incentives to reveal farmers private information by providing discrimination contracts with an additional payment for one of the farmers (and possibly a change in the share of irrigated land) in order to incentivize some others to behave truthfully. When the regulator is unable to observe farms' hidden action, the regulator could impose a monitoring strategy by involving sanction as an instrument to incentivize farmers to be compliant with their statement as long as this mechanism result cost-effective (i.e. monitoring costs are lower than the gain from the implementation of this tool).

Usually, the design of policy under incomplete information is complicated for the regulator because of costs incurred to guarantee its implementation. This study is promising for providing insights into how the regulation of irrigated agriculture is handled by WAs when facing incomplete information throughout the policy design process. However, more tractable results from empirical applications have yet to be considered and further investigated in order to provide evidence of the suitability of these solutions for more diffused implementation.

9. References

1. Aidam, W.P. 2015**.** The impact of water-pricing policy on the demand for water resources by farmers in Ghana. *Agric. Water Manag.* 158, 10–16 https://doi.org/10.1016/j.agwat.2015.04.007
2. ARCADIS. 2012. The role of water pricing and water allocation in agriculture in delivering sustainable water use in Europe. Final Report [CrossRef].
3. Arguedas, C. and van Soest, D. P. 2011. Optimal conservation programs, asymmetric information and the role of fixed costs. *Environ Resource Econ* 50: 305. https://doi.org/10.1007/s10640-011-9474-x
4. Bartolini, F., Bazzani, G. M., Gallerani, V., Raggi, M., Viaggi, D. 2007. The impact of water and agriculture policy scenarios on irrigated farming systems in Italy: an analysis based on farm level multi-attribute linear programming models. *Agric. Syst* 93: 90-114 https://doi.org/10.1016/j.agsy.2006.04.006
5. Bazzani, G.M., Di Pasquale, S., Gallerani. and Viaggi, D. 2004. Irrigated agriculture in Italy and water regulation under the European Union water framework directive. *Water Resource Research* 407: W07S04 doi`:10.1029/2003WR002201
6. Bazzani, G.M. 2005. A decision support for an integrated multi-scale analysis of irrigation: DSIRR. *J. Environ. Manag* 77 4: 301-314 https://doi.org/10.1016/j.jenvman.2005.09.001
7. Bolton, P., Dewatripont, M. 2005. *Contract theory*. The MIT Press, Cambridge, Massachusetts, London, 2005**,** 12-169, ISBN 0-262-02576-0.
8. Bournaris, T., Berbel, J., Manos, B., Viaggi, (Eds.) 2015. Economics of Water Management in Agriculture., CRS Press. Boca Ratorn, FL, USA
9. Barouchas, P. E., Tsirogiannis, Y.L., Malamos, N. (Edis.) 2015. Efficient irrigation management and its effects in urban and rural landscapes. *Agriculture and Agricultural Science Procedia.* DOI: 10.1016/j.aaspro.2015.03.011
10. Choe, C., Fraser, I. 1998. A note on imperfect monitoring of agri-environmental policy. *Journal of Agricultural Economics, 49,* 250-258 CrossRef.
11. Dinar, A., Pochat, V., Albiac, J. (Eds.) 2015. Water pricing experiences and innovations. Global Issues in Water Policy. Riverside , CA, USA
12. Dinar, A. and Mody, J. 2004. Irrigation water management policies: Allocation and pricing principles and implementation experience. *Natural Resources Forum* 28: 112–122 DOI: 10.1111/j.1477-8947.2004.00078.x
13. Dinar, A. and Subramanian, A. 1998. Policy implications from water pricing experiences in various countries. *Water Policy* 12: 239-250 https://doi.org/10.1016/S1366-7017(98)00011-7
14. Dinar, A., Pochat, V., Albiac, J. 2015. *Water Pricing Experiences and Innovations*, Springer: Cham, Switzerland.
15. Dinar, A, Subramanian, A. (Eds.) 1997. *Water pricing experiences : an international perspective*. World Bank technical paper, no. WTP 386. Washington, D.C. The World Bank.
16. Dono, G., Giraldo, L., Severino, S. 2010. Pricing of irrigation under alternative charging methods: possible shortcomings of a volumetric approach. *Agricultural Water Management* 97: 1795–1805. http://dx.doi.org/10.1016/j.agwat.2010.06.013

17. Dridi, C., Khanna, M. 2005. Irrigation technology adoption and gains from water trading under asymmetric information. *American Journal of Agricultural Economics* 87 (2): 289-301 https://doi.org/10.1111/j.1467-8276.2005.00722.x
18. Easter, K. W., Liu, Y. 2005. Cost recovery and water pricing for Irrigation and drainage projects. Agriculture and Rural Development Discussion Paper 26 CrossRef
19. EEA. 2017. Water management in Europe: price and non-price approaches to water conservation. Water management.
20. EEA. 2013. Assessment of cost recovery through water pricing. Report No. 16. Copenhagen, Denmark CrossRef
21. Elnaboulsi, J. C., (2009). An incentive water pricing policy for sustainable water use. *Environ Resource Econ, 42, 451-469 https://doi.org/10.1007/s10640-008-9218-8*
22. ENTEC. 2010. *Managing scarce water resources – Implementing the pricing policies of the WFD*. Final Report. London. Report for the European Commission - DG Environment CrossRef
23. Erik, G. 2015. Cost recovery for water services in the EU. *Water services* DOI: 10.1007/s10272-015-0523-5
24. European Commission, 2012a. Commission Staff Working Document, European Overview 1/2 Accompanying the Document: "Report From the Commission to the European Parliament and the Council on the Implementation of the Water Framework Directive 2000/60/EC River Basin Management Plans". COM 2012 670 Final.
25. European Commission. 2000. DIRECTIVE 2000/60/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 October 2000 establishing a framework for Community action in the field of water policy. *Official Journal of the European Communities*
26. European Commission. 2015. Report on the Progress in Implementation of the Water Framework Directive – Programmes of Measures. Commission Staff Working Document, Brussels, Belgium, [CrossRef].
27. European Commission. 2012. *A Blueprint to Safeguard Europe's Water Resources. COM2012 673 Final*, EC: Brussels, Belgium.
28. European Union. 2000. Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 Establishing a Framework for Community Action in the Field of Water Policy. p. 1 OJ L 327, 22.12.2000, 1.
29. Expósito, A., and Berbel, J. 2016. Why is water pricing ineffective for deficit irrigation schemes? A case study in southern Spain. *Sustainability* 9, 1144; doi:10.3390/su9071144
30. Expósito, A., Berbel, J. 2017. Why is water pricing ineffective for deficit irrigation schemes? a case study in southern Spain. *Water Resources Management* 313: 1047-1059 DOI: 10.1007/s11269-016-1563-8
31. FAO. 2004. Water charging in irrigated agriculture. An analysis of international experience. Prepared by G. Cornish, B. Bosworth, C. Perry and J. Burke. FAO Water Reports, no. 28.
32. Fragoso, M. S. R., Marques, A. F. C. 2015 Alternative irrigation water pricing policies: An econometric mathematical programming model. *New Medit. Mediterranean Journal of Economics, Agriculture and Environment* 14: 42-49 [CrossRef].
33. Franco-Crespo, C. and Vinas. S. M. J. 2017. The impact of pricing policies on irrigation water for agro-food farms in Ecuador. *Sustainability* 99: 1515 doi: 10.3390/su9091515
34. Fraser, R. 2013. Presidential address to cheat or not to cheat: Moral hazard and agri-environmental policy. *Journal of Agricultural Economics* 6: 527–536 [CrossRef].

35. Frija, A., Wossink, A., Buysse, J., Speelman, S., Huylenbroeck, G. 2011. Irrigation pricing policies and its impact on agricultural inputs demand in Tunisia: A DEA-based methodology. *Journal of Environmental Management* 92: 2019-2118, [CrossRef].
36. Galioto, F., Raggi, M., Viaggi, D. 2015. Incentive pricing for irrigation water with asymmetric information. In *Economics of water management in agriculture*. (Eds.) Bournaris, Th., Berbel, J., Manos, B. and Viaggi, D. CRS Press 2015, 168-188, 978-1-4822-3839-6.
37. Galioto, F., Raggi, M., Viaggi, D. 2013. Pricing policies in managing water resources in agriculture: An application of contract theory to unmetered water. *Water* 5: 1502-1516 [CrossRef].
38. Gallerani, V., Raggi, M. and Viaggi, D. 2005. Pricing irrigation water under asymmetric information and cost recovery constraint. *Water Science and Technology: Water Supply* 56: 189-196 CrossRef
39. Garrido, A., Calatrava, J. 2010. Agricultural Water Pricing: EU and Mexico. OECD
40. Giannakis, E., Bruggeman, A., Djuma, H., Kozyra, J. and Hmmer, J. 2016. Water pricing and irrigation accros Europe: opportunity and constraints for adopting irrigation scheduling decision support systems. *Water Science & Technology: Water Supply* 16.1: 245-252. doi: 10.2166/ws.2015.136
41. Giannoccaro, G., Prosperi, M., Zanni, G. 2010. Assessing the impact of alternative water pricing schemes on income distribution. *Journal of Agricultural Economics* 61: 527-544 [CrossRef].
42. Gomez-Limon, J. A. and Riesgo, L. 2012. Agriculture and economics in the Water Framework Directive: progress and limitations. *Water Policy* 14: 31–14 CrossRef
43. Gomez-Limon, J.A., Berberl, J. 2000. Multicriteria analysis of derived water demand functions: A Spanish case study. *Agric. Syst* 63: 49–71 https://doi.org/10.1016/S0308-521X(99)00075-X
44. Grimble, J. R. 1999. Economic instruments for improving water use efficiency: theory and practice. *Agriculture Water Management* 40: 77-82 https://doi.org/10.1016/S0378-3774(98)00107-3
45. Groenfeldt, D., Sun, D. 1997. The concept of participatory irrigation management. *New Med* 2/97 CrossRef
46. Hanjra, M.A., Qureshi, M.E. 2010. Global water crisis and future food security in an era of climate change. *Food Policy* 35: 365–377 https://doi.org/10.1016/j.foodpol.2010.05.006
47. Ismaili, H. 2010. *Participatory Irrigation Management in Albania*, Ministry of Agricultural, Food and Consumer Protection: Tirane, Albania.
48. Johansson, R. C., Tsur, Y., Roe, L. T., Doukkali, R., Dinar, A. 2002. Pricing irrigation water: a review of theory and practice. *Water Policy* 4: 173-199 CrossRef
49. Kampragou, E., Apostolaki, S., Manoli, E., Froebrich, J., Assimacopoulos, D. 2011. Towards the harmonization of water-related policies for managing drought risks across the EU. *Environ Sci Policy* 147: 815–824 https://doi.org/10.1016/j.envsci.2011.04.001
50. Laffont, J.J., Martimort, D. 2002. The Rent Extraction-Efficiency Trade-off. In *The Theory of Incentives: The Principal Agent Model*, Princeton University Press: Princeton, NJ, USA,.
51. Lika, A., Galioto, F., Scardigno, A., Zdruli, P., Viaggi, D. 2016. Pricing unmetered irrigation water under asymmetric information and full cost recovery. *Water* 8, 596 CrossRef
52. Lika, A., Galioto, F., Viaggi, D. Water authorities' pricing strategies to recover supply costs in the absence of water metering for irrigated agriculture. *Sustainability*, **2017**, 2210 doi:10.3390/su9122210
53. Hart, R., Latacz-Lohmann, L. 2005. Combating moral hazard in agri-environmental schemes: a multiple-agent approach. *European Review of Agricultural Economics* 321:75-91 doi:10.1093/erae/jbi002

54. Masseroni, D., Ricart, S., de Cartagena, F.R., Monserrat, J., Gonçalves, J.M., de Lima, I., Facchi, A., Sali, G., Gandolfi, C. 2017. Prospects for improving gravity-fed surface irrigation systems in Mediterranean European contexts *Water* 9, 1, 20 DOI: 10.3390/w9010020
55. Millock, K., Xabadia, A., Zilberman, D. 2012. Policy for the adoption of new environmental monitoring technologies to manage stock externalities. *Journal of Environmental Economics and Management* 64: 102-116 CrossRef
56. Molle, F. 2009. Water scarcity, prices and quotas: a review of evidences on irrigation volumetric pricing. *Irrg Drainage Syst* 23: 43-58 CrossRef
57. Molle, F., Venot, J.P. and Hassan, Y. 2008.Irrigation in the Jordan Valley: are water pricing policies overly optimistic? *Agr. Water Manage* 95 (4): 427–438
58. Molle, F., Berkoff, J. 2007. Water pricing in irrigation: Mapping the debate in the light of experience. In *Irrigation water pricing. The gap between theory and practice*. Molle, F., Berkoff, J. Ed. London, UK 21-93 CrossRef
59. Moxey, A., White, B., 1998. Ozanne, A. Efficient contract design for agri-environmental policy, *Journal of Agricultural Economics* 49: 187-202 CrossRef
60. OECD. 2010b. Sustainable management of water resource in agriculture.
61. Omid, B., Malmir, M., Mohammad-Azari, S., Loáiciga, A. H. 2016. Estimation of farmers' willingness to pay for water in the agricultural sector. *Agricultural Water Management* 177: 284-290, https://doi.org/10.1016/j.agwat.2016.08.011.
62. Ozanne, A. and White, B. 2008. Hidden action, risk aversion and variable fines in agri-environmental schemes. *The Australian Journal of Agricultural and Resource Economics* 52: 203-212 DOI: 10.1111/j.1467-8489.2008.00408.x
63. Ozanne, A., Hogan, T. and Colman, D. 2001. Moral hazard, risk aversion and compliance monitoring in agri-environmental policy. *European Review of Agricultural Economics* 28: 329–347 https://doi.org/10.1093/erae/28.3.329
64. Qureshi, E. M., Ranjan, R. and Qureshi, E. S. 2010. An empirical assessment of the value of irrigation water: the case study of Murrumbidgee catchment. *The Australian Journal of Agricultural and Resource Economics* 54: 99-118 doi: 10.1111/j.1467-8489.2009.00476.x
65. Rogers, A., Bhatia, R., Huber, A. 1998. Water as a social and economic good: How to put the principle into practice. *Glob. Water Partnership* 2, 35 CrossRef
66. Rothkopf, A., Pibernik, R. 2016. Maverick buying: Eliminate, participate, leverage? *Int. J. Production Economics* 179: 77–89 CrossRef
67. S.K. Sun, C. Li, P.T. Wu, X.N. Zhao, Y.B. Wang. 2018 Evaluation of agricultural water demand under future climate change scenarios in the Loess Plateau of Northern Shaanxi, China, *In Ecological Indicators* 84: 811-819 https://doi.org/10.1016/j.ecolind.2017.09.048
68. Sagardoy, J.A, C. Varela-Ortega. 2010. Present and future roles of water and food trade in achieving food security, reducing poverty and water use. In L. Martínez-Cortina, A. Garrido, E. López-Gunn Eds., Re-thinking Water and Food Security. Fourth Marcelino Botín Water Workshop, Taylor & Francis, London, 109–144
69. Salanie, B. 2005. *The economics of contracts.* The MIT Press, Cambridge, London, England.
70. Savenije, H. and van der Zaag., P. 2002. Water as an economic good and demand management paradigms with pitfalls. International Water Resources Association. *Water International* 271: 98–104 https://doi.org/10.1080/02508060208686982

71. Shen, D., Reddy, V. R. 2016. Water pricing in China and India: a comparative analysis. *Water Policy*, 18 (S1): 103-121 DOI: 10.2166/wp.2016.107
72. Smith, R.B.W., Tsur, Y. 1997. Asymmetric information and pricing natural resource: understanding the case of unmetered water. *Land Economics* 97: 1326-1332 [CrossRef]
73. Speelman, S., Buysse, J., Farolfi, S., Frija, A., D'Haesa, M., D'Haesa, L. 2009. Estimating the impacts of water pricing on smallholder irrigators in North West Province, South Africa. *Agricultural Water Management* 96: 1560-1566, [CrossRef]
74. Teodosiu, C., Barjoveanu, G., Teleman, D., 2003. Sustainable water resources management 1. River basin management and the EC Water Framework Directive. *Environ. Eng. Manag. J.* 2: 377–394.
75. Thivet, G., Fernandez, S., 2012. Water demand management. The Mediterranean experience. Technical focus paper. *Global water partnership*. UK
76. Tiwari, D. and Dinar, A. 2003. The role and use of economic incentives in irrigated agriculture. Working paper, World Bank, Washington, D.C.
77. Tiwari, Dirgha, Dinar, Ariel. 2000. Role and use of economic incentives in irrigated agriculture. Washington, DC: World Bank. http://documents.worldbank.org/curated/en/688561468779666802/Role-and-use-of-economic-incentives-in-irrigated-agriculture
78. Toan, T.D. 2016 Water pricing policy and subsidies to irrigation: A review. *Environ. Processes* 3: 1081–1098 [CrossRef]
79. Tsur, Y. and Dinar, A. 1997. "On the Relative Efficiency of Alternative Methods for Pricing Irrigation Water and Their Implementation." *World Bank Economic Review*, 11: 243-262.
80. Tsur, Y. 2000. Water regulation via pricing: The role of implementation costs and asymmetric Information. In *The Political Economy of Water Pricing Reforms*, Dinar, A., (Eds.), Oxford University Press: Oxford, UK, 2000, pp. 105–120.
81. Tsur, Y. 2004, Introduction to special section on Irrigation Water Pricing, *Water Resour. Res*., 40, W07S01 DOI: 10.1029/2003WR002213
82. Tsur, Y., Roy, T., Doukkali, R., Dinar, A., 2010. Pricing irrigation water: Principles and cases from developing countries. Washington, DC, USA
83. 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. *Agric. Econ.* 19: 193–202 [CrossRef]
84. Vasileiou, K., Mitropoulos, P., Mitropoulos, I. 2014. Optimizing the performance of irrigated agriculture in eastern England under different water pricing and regulation strategies. *Nat. Res. Model 27*: 128–150 DOI: 10.1111/nrm.12022
85. Vedel, E. S., Lund, D. H., Jacobsen, B. j., Helles, F. 2006. Grants for advisory services in the private Danish forestry sector – A principal–agent approach. *Journal of Forest Economics* 12: 185–199 https://doi.org/10.1016/j.jfe.2006.08.001
86. Viaggi, D., Raggi, M., Bartolini, F., Gallerani, V. 2010. Are simple pricing mechanisms enough? Designing contracts for irrigation water under asymmetric information in an area of Northern Italy. *Agric. Water Manag* 97: 1326–1332, [CrossRef]
87. Voulvoulis, N., Arpon, K.D., Giakoumis, T. 2017. The EU Water Framework Directive: From great expectations to problems with implementation, *SCIENCE OF THE TOTAL ENVIRONMENT* 575: 358-366 DOI: 10.1016/j.scitotenv.2016.09.228

88. White, B. 2002. Designing voluntary agri-environmental policy with hidden information and hidden action: a note. *Journal of Agricultural Economics* 53 (2): 353–360 CrossRef
89. World Bank. 1993. Water resource management. Washington DC. USA

10. Appendix

10.1 Appendix 2.1

Practical implementation of water pricing across EU states

<table>
<tr><td>Austria</td><td>Mixed tariff: fixed charge and volumetric charge.
Tariff system vary however between regions.</td></tr>
<tr><td>Belgium</td><td>Mixed tariff: fixed charge (diameter of pipe) and volumetric (decreasing) block tariffs.
Fixed administrative charge (varying per municipality) and flat volumetric (Brussel Region)
Combined tariff (Walloon Region):
Fixed charge for renting of water meter
Decreasing volumetric tariff</td></tr>
<tr><td>Bulgaria</td><td>No uniform pricing system nationwide. Total irrigation water prices depend on the sourcing of irrigation (gravity or pump). Each IWUA (Irrigation Water Use Association) uses a different method to calculate and set price).
Area based charge
Volumetric charge</td></tr>
<tr><td>Cyprus</td><td>Government / Public schemes for irrigation: Flat volumetric tariff with varying price levels (use). No differentiation between areas. Differentiated tariffs for bulk supply to irrigator's organizations and for individual farmers (latter: higher tariffs). Different (lower) tariff for water provided from treated sewage effluent. Overconsumption charged at a price multiple of the regular prices.
Irrigation divisions and non-governmental suppliers: no charge by the government.
Usually volumetric charge, considering total financial costs of abstraction and relevant utilities.
Area based charging or charge based on irrigation time exists in some small irrigation divisions abstracting water from the few natural surface water sources (small rivers).</td></tr>
<tr><td>Czech Republic</td><td>Water tariffs from public water supply systems are regulated by law: mixed tariff system, fixed charge and a volumetric charge above a threshold level.</td></tr>
<tr><td>Finland</td><td>Agricultural water (e.g. livestock and dairy farming) from public piped water supply system: Mixed system of fixed charge and volumetric charge</td></tr>
<tr><td>France</td><td>For non-gravity fed systems: mixed (binomial) tariff is most commonly used (fixed part based on area and volumetric part based on water use
Flat gravity fed irrigation systems</td></tr>
</table>

Germany	• Mixed system: fixed charge and volumetric charge for public water supply
Greece	• Flat rate (area-based) tariffs (predominant) • Volumetric charging (less frequent)
Hungary	Price is set by the supplier and divided in three parts: • Resource fee • Delivery charge (usually region based and volume based minimum supply charge) • Costs of 'watering' (maintenance costs, energy costs, wages)
Ireland	Mixed tariff: • Volumetric charge: all non-domestic users are charged based on volumetric usage • Farmers using pubic water supplies pay a standard charge for the installation and operation of a water meter.
Italy	*Consorzi di bonifica e irrigazione* (RIB or Irrigation Boards). Pricing systems are established independently in each RIB leading to a wide variety of different systems in place, even in closely located areas (depending on volume, type of cultivation or type of irrigation). • Flat rate (per hectare) water charges are predominant (very different between regions) • Volumetric charge is very rare and usually includes in a mixed system: an area rate and volumetric charge ***Sardinia***: water price depending on three variables: • type of irrigation • type of cultivation • size of area
Luxembourg	• Flat volumetric charging (water supply differ by municipality but are calculated on a harmonized methodology)
Malta	• Flat rate • Flat volumetric tariff
Poland	• Mixed system: fixed charge and a volumetric charge • Flat rate (per hectare) water charge

Portugal	Water Resources Levy (since 2008) constitutes of different components. Additionally, complex mechanism of charging by water users' associations (WUA) exist:
	• Mixed system of fixed charge and volumetric charge
	  o Fixed charge per hectare ameliorated or reclaimed land
	  o Fixed charge for irrigation hectare
	  o Volumetric charge

	◦ Drainage fee, when drainage of excessive water needed ◦ Crop-based fee application for specific crops and projects
Romania	Water prices differ according to use, also within the agriculture sector itself. The price is a volumetric charge and reflects a contribution for using the water resource and the water management system.
Slovak Republic	Negotiated prices for water supply on average 0,031 €/m³ and maximum 0,046 €/m³ regardless of the type of use.
Spain	• Area based fee Additional tariff is imposed by ID to cover the costs of the District itself. Legislation allows payment by volume, surface or mixed. Several approaches prevail: • Annual fee per hectare (flat rate) • Mixed system: fixed charge + variable charge • Irrigation-even fee • Volumetric tariffs

10.2 Appendix 3.4.2

The optimization problem facing the water regulator now is subject of binding constraints

$$\max_{\{t_1,x_1;t_2,x_2\}} S = \delta[(\pi_1(x_1) - c(x_1) - vt_1] + (1-\delta)[(\pi_2(x_2) - c(x_2) - vt_2] \quad \text{A.3.13}$$

s.t:

$$CR_1: t_1 \geq c(x_1) + vt_1 \quad \text{A.3.14}$$

$$CR_2: t_2 \geq c(x_2) + vt_2 \quad \text{A.3.15}$$

$$IC_1\ \pi_1(x_1) - t_1 \geq \pi_1(x_2) - t_2 \quad \text{A.3.16}$$

$$IC_2\ \pi_2(x_2) - t_2 \geq \pi_2(x_1) - t_1 \quad \text{A.3.17}$$

The corresponding Kuhn-Tucker conditions are:

$$\max_{\{t_1,x_1;t_2,x_2\}} S = \delta[(\pi_1(x_1) - c(x_1) - vt_1] + (1-\delta)[(\pi_2(x_2) - c(x_2) - vt_2] \quad \text{A.3.13}$$

$$+\mu_1[(1-v)t_1 - c(x_1)]$$

$$+\mu_2[(1-v)t_2 - c(x_2)]$$

$$+\mu_3[\pi_1(x_1) - t_1 - \pi_1(x_2) + t_2]$$

$$+\mu_4[\pi_2(x_2) - t_2 - \pi_2(x_1) + t_1]$$

$$\frac{dL}{dt_1} = -\delta v + \mu_1(1-v) - \mu_3 + \mu_4 = 0 \quad \text{A.3.13a}$$

$$\mu_1 = \frac{\delta v + \mu_3 - \mu_4}{(1-v)}; -\delta v + \mu_1(1-v) + \mu_4 = \mu_3$$

$$\frac{dL}{dt_2} = -(1-\delta)v + \mu_2(1-v) + \mu_3 - \mu_4 = 0 \quad \text{A.3.13b}$$

$$\mu_2 = \frac{(1-\delta)v - \mu_3 + \mu_4}{(1-v)}; -(1-\delta)v + \mu_2(1-v) + \mu_3 = \mu_4$$

$$\frac{dL}{dx_1} = \delta\big(\pi_1'(x_1) - c'(x_1)\big) - \mu_1 c'(x_1) + \mu_3\pi_1'(x_1) - \mu_4\pi_2'(x_1) = 0 \quad \text{A.3.13c}$$

$$\frac{dL}{dx_2} = (1-\delta)\big(\pi_2'(x_2) - c'(x_2)\big) - \mu_2 c'(x_2) - \mu_3\pi_1'(x_2) + \mu_4\pi_2'(x_2) = 0 \quad \text{A.3.13d}$$

$$\frac{dL}{d\mu_1} = [(1-v)t_1 - c(x_1)] = 0; \mu_1 \geq 0; [(1-v)t_1 - c(x_1)] \geq 0 \quad \text{A.3.13e}$$

$$\frac{dL}{d\mu_2} = [(1-v)t_2 - c(x_2)] = 0; \mu_2 \geq 0; [(1-v)t_1 - c(x_1)] \geq 0 \quad \text{A.3.13f}$$

$$\frac{dL}{d\mu_3} = [\pi_1(x_1) - t_1 - \pi_1(x_2) + t_2] = 0; \mu_3 \geq 0; [\pi_1(x_1) - t_1 - \pi_1(x_2) + t_2] \geq 0 \quad \text{A.3.13g}$$

$$\frac{dL}{d\mu_4} = [\pi_2(x_2) - t_2 - \pi_2(x_1) + t_1] = 0; \mu_4 \geq 0; [\pi_2(x_2) - t_2 - \pi_2(x_1) + t_1] \geq 0 \quad \text{A.3.13h}$$

From the assumption that CR_i binds can be considered that $\mu_1 > 0$ and $\mu_2 > 0$ and from equations A.3.13e and A.3.13f is received:

$$[(1-v)t_1 - c(x_1)] = 0; t_1 = \frac{c(x_1)}{(1-v)}$$

$$[(1-v)t_2 - c(x_2)] = 0; t_2 = \frac{c(x_2)}{(1-v)}$$

Given the assumption that IC_i does not bind, the conditions A.3.13a to A.3.13d further reduce two:

$\mu_1 = \frac{\delta v}{(1-v)}$

$\mu_2 = \frac{(1-\delta)v}{(1-v)}$

$\frac{dL}{dx_1} = \delta\big(\pi_1'(x_1) - c'(x_1)\big) - \frac{\delta v}{(1-v)}c + \mu_3\pi_1'(x_1) - \mu_4\pi_2'(x_1) = 0$

$\frac{dL}{dx_2} = (1-\delta)\big(\pi_2'(x_2) - c'(x_2)\big) - \frac{(1-\delta)v}{(1-v)}c - \mu_3\pi_1'(x_2) + \mu_3\pi_2'(x_2) = 0$

$\frac{dL}{dx_1} = \delta\big(\pi_1'(x_1) - c'(x_1)\big) - \frac{\delta v}{(1-v)}c'(x_1) = 0$

$\frac{dL}{dx_2} = (1-\delta)\big(\pi_2'(x_2) - c'(x_2)\big) - \frac{(1-\delta)v}{(1-v)}c'(x_2) = 0$

From the above equation, the following fist best optimal solution is achieved:

$\pi_1'(x_1) = \frac{c\prime(x_1)}{(1-v)}$

$\pi_2'(x_2) = \frac{c\prime(x_2)}{(1-v)}$

Figure A.3.4.2 shows the corresponding optimal solution for each farm type is achieved at the point where indifference curves are tangent with the profit curves.

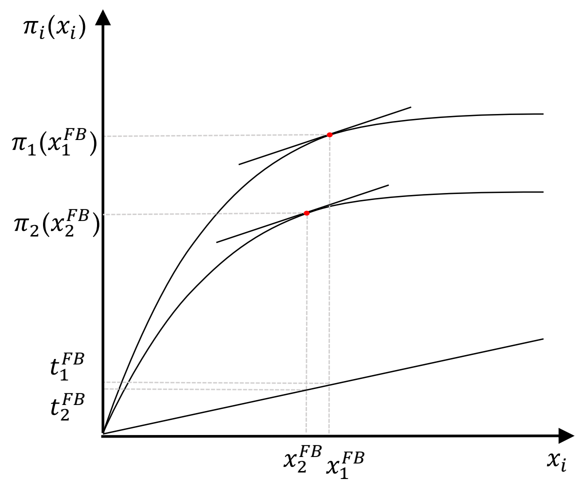

Figure A.3.4.2. Illustration of the optimal irrigated share, water tariffs and profit for each farm type

Let's check why the IC does not bind and evaluate if the cost function (i.e. $c'(x_1) = c'(x_2)\ \forall\ x$) taken for both types equal impacts the reached solution.

Suppose that individual farmer has private information and act strategically to maximize his benefit and consider that its benefit depends only from the choice he makes. In addition, the farmer is aware about costs and benefits facing in function of his decision. In doing so, is assumed that the farm type $i \in n = 1, 2$ has tow possible strategies $\mathcal{M}_{1,2}$ and his net benefit varies in function of his chosen strategy $V_i(\mathcal{M}_1, \mathcal{M}_2)$, considering that farmers act opportunistically and behave as a profit maximizes, without loss of generality, $V_1(\mathcal{M}_1) = \pi_1(x_1) - t_1; V_1(\mathcal{M}_2) = \pi_1(x_2) - t_2; V_2(\mathcal{M}_1) = \pi_2(x_2) - t_2; V_2(\mathcal{M}_2) = \pi_2(x_1) + t_1$. The strategy choice is the one that maximizes his net benefit which is in function of the irrigated share x_i and water tariff t_i.

If considered that the IC_1 binds in optimum then can be written in the following form:

$\pi_1(x_1) - t_1 = \pi_1(x_2) - t_2$

$\pi_1(x_1) - t_1 - \pi_1(x_2) + t_2 = 0$

From assumption, is known that CR1 binds with strict equality.

$t_1 = c(x_1) + vt_1$

$$t_1 = \frac{c(x_1)}{1 - v}$$

Substituting the value of t in the IC and writing in the form of FCO with respect to x the solution is:

$\pi_1'(x_1) - \frac{c\prime(x_1)}{1-v} - \pi_1'(x_2) + \frac{c\prime(x_2)}{1-v} = 0$

Simplification of the above equation yield to:

$\pi_1'(x_1) - \pi_1'(x_2) = 0$

From the assumption of properties of profit functions this statement $\pi_1'(x_1) - \pi_1'(x_2) = 0$ cannot be true. The hypothesis indicates that the cost function is assumed linear on x for both types, which implies that $c'(x_1) = c'(x_2)$ and $c'(x_i) > 0$ and $c''(x_i) = 0$ and farm's profit function is concave and increasing along the x. Eventually involves $\pi_i(x_i) \neq \pi_i(x_j)\ \forall\, x_i$ (see. Figure A. 3.4.2) and $\pi_i'(x_i) > 0$ and $\pi_i''(x_i) \leq 0$. Which eventually makes $\pi_1'(x_1) \neq \pi_1'(x_2)$

Therefore the incentive constraint does not bind for both types and the solution implies $V_1 \mid \mathcal{M}_1(x_1, t_1) > V_1 \mid \mathcal{M}_2\ (x_2, t_2)$ (i.e. $V_2|\mathcal{M}_1(x_2, t_2) > V_2 \mid \mathcal{M}_1(x_2, t_2)$ and this proof hold for both IC.

10.3 Appendix 3.4.4

The optimization problem facing the water regulator now is subject of binding constraints

$$\max_{\{t_1,x_1;t_2,x_2\}} S = \delta_1[(\pi_1(x_1) - c_1(x_1) - vt_1] + \delta_2[(\pi_2(x_2) - c_2(x_2) - vt_2]$$

s.t:

CR1: $t_1 \geq c_1(x_1) + vt_1$
CR2: $t_2 \geq c_2(x_2) + vt_2$
IC1: $\pi_1(x_1) - t_1 \geq \pi_1(x_2) - t_2$
IC2: $\pi_2(x_2) - t_2 \geq \pi_2(x_1) - t_1$

The water authority wants to impose the most social welfare-maximizing menu of contracts. The water regulator know that he bears higher water supply costs from high productivity farmer and he is less willing to make a restriction to him and the water authority imposes a more restriction criteria to the low productivity type by making IC1 to be biding which inevitably make CR2 not binding[9]. In addition the purpose is to provide discrimination contracts

Rearranging the above Kuhn-Tucker conditions and adjusting with respect to different cost function for each type, under binding constraints the following solution is achieved:

$$\mu_1 = \frac{\delta v + \mu_3 - \mu_4}{(1-v)}$$

$$\mu_3 = (1-\delta)v$$

$$\mu_1 = \frac{v}{(1-v)}$$

$$\frac{dL}{dx_1} = \delta\big(\pi_1'(x_1) - c_1'(x_1)\big) - \mu_1 c_1'(x_1) + \mu_3 \pi_1'(x_1) - \mu_4 \pi_2'(x_1) = 0$$

$$\delta\big(\pi_1'(x_1) - c_1'(x_1)\big) - \mu_1 c_1'(x_1) + \mu_3 \pi_1'(x_1) = 0$$

$$\delta\pi_1'(x_1) + \mu_3\pi_1'(x_1) - \left(\delta + \frac{v}{(1-v)}\right) c_1'(x_1) = 0$$

$$\pi_1'(x_1) + \frac{1-\delta}{\delta} v\, \pi_1'(x_1) - \left(1 + \frac{v}{(1-v)\delta}\right) c_1'(x_1) = 0$$

$$(\delta - \delta v + v)\pi_1'(x_1) - \left(\frac{\delta - v\delta + v}{(1-v)}\right) c_1'(x_1) = 0$$

$$\frac{\delta + (1-\delta)v}{\delta}\, \pi_1'(x_1) - \left(\frac{(1-v)\delta + v}{(1-v)\delta}\right) c_1'(x_1) = 0$$

$$(\delta - \delta v + v)\pi_1'(x_1) - \left(\frac{\delta - v\delta + v}{(1-v)}\right) c_1'(x_1) = 0$$

$$\pi_1'(x_1^*) = \frac{c_1'(x_1^*)}{1-v} \qquad \text{(A.3.22)}$$

$$\frac{dL}{dx_2} = (1-\delta)\big(\pi_2'(x_2) - c_2'(x_2)\big) - \mu_2 c_2'(x_2) - \mu_3 \pi_1'(x_2) + \mu_4 \pi_2'(x_2) = 0$$

$$\big(\pi_2'(x_2) - c_2'(x_2)\big) - v\pi_1'(x_2) = 0$$

[9] In this setting is disregarded the option of imposing restriction criteria on the input as it is provided in the most of the literature.

$$\left(\pi_2'(x_2) - c_2'(x_2)\right) - v[\pi_1'(x_2)] = 0$$

$$(1 - v)\pi_2'(x_2) = c_2'(x_2) + v[\pi_1'(x_2) - \pi_2'(x_2)]$$

$$\pi_2'(x_2) = \frac{c_2'(x_2)}{(1 - v)} + \frac{v}{(1 - v)}[\pi_1'(x_2) - \pi_2'(x_2)] \qquad \text{(A.3.23)}$$

10.4 Appendix 3.4.5

$\mu_1 = \frac{v-\mu_2(1-v)}{(1-v)}$

$\mu_3 \ = (1-\delta)v - \mu_2(1-v)$

$\mu_2 = \frac{(1-\delta)v-\mu_3}{(1-v)}$

$\delta\big(\pi_1'(x_1) - c_1'(x_1)\big) - \left(\frac{v-\mu_2(1-v)}{(1-v)}c_1'(x_1)\right) + \big((1-\delta)v - \mu_2(1-v)\big)\pi_1'(x_1) = 0$

$(\delta + (1-\delta)v - (1-v)\mu_2)\pi_1'(x_1) - \left(\frac{v-\mu_2(1-v)+(1-v)\delta}{(1-v)}c_1'(x_1)\right) = 0$

$(\delta + v - v\delta - (1-v)\mu_2)\pi_1'(x_1) - \left(\frac{\delta+v-v\delta-(1-v)\mu_2}{(1-v)}c_1'(x_1)\right) = 0$

$$\pi_1'(x_1^*) = \frac{c_1'(x_1^*)}{1-v} \qquad \text{(A.3.22)}$$

$\frac{dL}{dx_2} = (1-\delta)\big(\pi_2'(x_2) - \ c_2'(x_2)\big) - \mu_2 c_2'(x_2) - \mu_3\pi_1'(x_2) + \mu_4\pi_2'(x_2) = 0$

$(1-\delta)\big(\pi_2'(x_2) - \ c_2'(x_2)\big) - \mu_2 c_2'(x_2) - \mu_3\pi_1'(x_2) + \mu_4\pi_2'(x_2) = 0$

$(1-\delta)\pi_2'(x_2) - \left((1-\delta) + \frac{(1-\delta)v-\mu_3}{(1-v)}\right)c_2'(x_2) - \mu_3\pi_1'(x_2) = 0$

$$\pi_2'(x_2) = \frac{c_2'(x_2)}{(1-v)} + \frac{\mu_3}{(1-\delta)}\left[\pi_1'(x_2) - \frac{c_2'(x_2)}{(1-v)}\right] = 0 \qquad \text{(A.3.24)}$$

10.5 Appendix 5.2.5

$$z = \pi(x) - c(x) - v\left(\frac{c(x)}{1-v} + \frac{\pi(x^*)-\pi(x)}{P_1-(1-P_0)}\right),$$
$$\frac{L}{dx} = \pi'(x) - c'(x) - v\left(\frac{c\prime(x)}{1-v} - \frac{\pi\prime(x)}{P_1-(1-P_0)}\right) = 0,$$
$$\frac{L}{dx} = \left(1 + \frac{v}{P_1-(1-P_0)}\right)\pi'(x) = \frac{c\prime(x)}{1-v},$$
$$\pi'(x) = \frac{c\prime(x)}{\left(1+\frac{v}{P_0-(1-P_1)}\right)(1-v)}, \tag{A.10}$$

10.6 Appendix 6.2.1

$$Z(x) = \pi(x) - c(x) - \delta\left(\frac{c(x)}{1-\delta}\right)$$

$$\frac{dZ}{dx} = \pi(x)' - c(x)' - \delta\left(\frac{c(x)'}{1-\delta}\right) = 0$$

$$\frac{dZ}{dx} = \pi(x)' - \left(1 + \frac{\delta}{1-\delta}\right)c(x)' = 0$$

$$\pi(x)' = \frac{c(x)'}{(1-\delta)} \quad \text{(A.7)}$$

10.7 Appendix 6.2.2

$$Z\big(x,t,P(m)\big) = \pi(x) - c(x) - \delta\left(\frac{c(x)+km}{(1-\delta)} + \frac{\pi(x^{PR})-\pi(x)}{P(m)}\right) - km$$

$$\frac{dZ}{dx} = \pi(x) - c(x) - \delta\left(\frac{c(x)+km}{(1-\delta)} + \frac{\pi(x^{PR})-\pi(x)}{P(m)}\right)$$

$$\frac{dZ}{dx} = \pi(x)' - c(x)' - \delta\left(\frac{c(x)'}{(1-\delta)} - \frac{\pi(x)'}{P(m)}\right) = 0$$

$$\pi(x)' - c(x)' - \frac{\delta\, c(x)'}{(1-\delta)} + \frac{\delta\pi(x)'}{P(m)} = 0$$

$$\left(1 + \frac{\delta}{P(m)}\right)\pi(x)' - \left(1 + \frac{\delta}{(1-\delta}\right) c(x)' = 0$$

$$\pi(x)' = \left(\frac{c(x)'}{\left(1+\frac{\delta}{P(m)}\right)(1-\delta)}\right)$$

$$\frac{dZ}{dP(m)} = \left(-\frac{\delta k}{(1-\delta)} + \frac{\big(\pi(x^{PR})-\pi(x)\big)P(m)'}{P(m)^2}\right) = 0$$

$$\left(\frac{\big(\pi(x^{PR})-\pi(x)\big)P(m)'}{P(m)^2}\right) = \frac{\delta k}{(1-\delta)} + k$$

$$P(m) = \sqrt{\frac{(k)}{\big(\pi(x^{PR})-\pi(x)\big)(1-\delta)P(m)'}}$$