University of Naples Federico II

Department of Agriculture Sciences

Ph.D. thesis in Sustainable Agricultural and Forestry Systems and Food Security

Identification of efficient water pricing criteria for sustainable irrigation systems. Evidence from southern Italy.

Ph.D. student: Laura Mirra

Ph.D supervisor: Prof. Guido D'Urso

Ph.D co-supervisor: Prof. Giacomo Giannoccaro

Prof.ssa Teresa Del Giudice

Dott.ssa Raffaella Zucaro

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INTRODUCTION

Water shortage is one of the mainly world issues and, considering climate change projections, it is going to be prominent in the coming years (UN WWDR, 2021).

Nowadays, an increased number of countries are already experiencing problem of water scarcity. Moreover, as argued in IPCC Special Report on emissions scenarios, climate change will induce variation in precipitation and temperature trends that, in turn, will translate into changes in runoff and water availability (Bates et al. 2008, Imenez Cisneros 2014).

Since water availability and accessibility are the most limiting factors for crop production, addressing this topic is essential for areas affected by water scarcity. Moreover, population growth, urbanization and production of intensive-water products (mostly agro-food products) will exacerbate the magnitude of stress on water resource. This is particularly true in the Mediterranean and semi-arid climate regions of developed countries such as Italy, Spain, Greece, Australia or western United States. The latter, share a common key factor: a competitive irrigated agriculture consuming up to 70% of total water use (Berbel et al., 2019).

There are a wide range of water policies tools to cope with this situation. However supply-side measures (i.e., rising in new infrastructure like reservoirs and waterways to meet increasing anthropic needs) are no longer a practicable option in regions with mature water economies, where further increases in resource availability are not feasible anymore both for economic (unaffordable investment costs) and environmental (conservation of water-related ecosystems) reasons. In these circumstances, water demand and water supply result to be strongly unbalanced. Therefore, water demands can be fulfilled by decreasing the existing ones by the means of demand-side instruments, such as water pricing, water trade (water markets and water banks) or promoting water-saving technologies (Gomez-Limon et al., 2020). In particular, water pricing has been generally envisaged as a valid water demand policy to help solve problems of efficient water allocation and competition.

In October 2000, the Water Framework Directive (WFD) established a common framework for water management in Europe, thereby substantially reforming European water legislation.

The WFD also prioritize the use of economic instruments to reach environmental goals by introducing new criteria for water management, i.e. regulation and pricing, including the full cost recovery and the polluter pays principles. In particular, according to article 9, the directive emphasizes the role of water pricing as a convenient economic instrument to enhance an efficient water management and conservation, and to encourage a rational use of the resource (Gomez-Limòn and Riesgo, 2004; Giannoccaro et al., 2010). However, the implementation of economic instruments and the level of full cost recovery is still far from desirable levels among EU countries. Many authors highlighted the critical issues of this tool in ensuring an appropriate fulfillment of the objectives set out in the Directive (Berkoff and Molle 2007, and Berbel et al., 2019).

In Italy, water management is entrusted to the regions, considered as responsible for the design and implementation of water taxation, including that of irrigation sector. More specifically, in agriculture it is possible to identify two main different irrigation water services, namely collective and self-supplied. The first one, is managed by reclamation irrigation board (RIB), public bodies in charge of defining water rights for irrigation; (i.e., how much water farmers can seasonally benefit from, when they can do so) and the water pricing policies (identification of water tariff scheme to recover the water distribution cost). The second one, mostly adopted to withdrawn from groundwater aquifers, is self-organized by the end users who pay for all financial cost for water supply abstraction and distribution. However, the latter is subject to public authorization or licensing controlled by regional Government. Hence, irrigation water management rely on two main tax instruments: (i) tariff and (ii) tax for non-regulated waters and self-service abstractions.

As regard to the Reclamation and irrigation board they have to recover service operational and maintenance costs, and the tariff charge varies according to the real cost of water supply (Berbel et al., 2019).

The extreme heterogeneity characterising the Italian irrigation sector prevent the adoption of uniform water pricing scheme (volumetric, area-based, input-based, and so on) (Zucaro, 2011). In general, a rather diversified and tendentially low level of cost recovery is observed, mostly during water scarcity condition. Furthermore, as argued by Perez-

Blanco et al. 2016 cost recovery becomes even more difficult during “dry-year hydrological conditions”.
A crucial aspect to consider in designing water charges systems of collective water service is the pervasive incentive towards the use of other water sources. This is particularly true in semi-arid regions, where conjunctive use of collective facilities and on-farm groundwater pumps may cause conflicts and mismanagement of water resources. An inappropriate change of payment system set-up by the Consortia can lead to an overexploitation of the aquifer by farmers. Among others, this effect translates into the salinization of coastal aquifers, worsening their quality and the ecosystem health.
Due to climate change these effects will soon be exacerbated. The increase in droughts will threaten accessibility to the water resource.
Under these circumstances, the design of new water pricing scheme taking more into account the effects of climate change both from an economic and environmental point of view become necessary to achieve the Directive’s goal.
In light of this, this Ph.D. thesis aims to contribute to this area of research designing a water pricing scheme able to guarantee an efficient water resource reallocation during hydrological drought condition in order to minimize negative economic impacts. The case study is located in the Consorzio di Bonifica della Capitanata (CBC), the largest irrigated area in South Italy. More specifically, the study focuses on the analysis of CBC revenue, water demand (both surface and groundwater) and farmer’s income located in the area.
The broad extent of research is aimed to support the public decision-maker in regulating the use of water resources, taking into account the multiple functions of the agricultural sector.
The methodology adopted is part of the ex-ante evaluation methods of water policies. More specifically, a positive mathematical programming model to simulate farmers’ behaviour is implemented. The method intends to provide a normative analysis devoted to reclamation consortia and basin authorities in charge of pricing policies implementation. Overall, the work was intended to contribute to the development of scientific knowledge regarding the methods of evaluation of water use management measures.

Background and objectives

This thesis project is fully part of the existing scientific debate about the Water Framework Directive and its implementation. As is well known, the European Directive has set itself the ambitious goal of bringing all community water bodies to a "good" ecological status. There are probably two major challenges affecting the irrigation sector: the quantification of irrigation volumes (Ursitti et al., 2018; Viaggi et al., 2010) and the introduction of a full cost recovery policy connected to the use of the resource (Berbel et al., 2019). The recovery of the full cost as defined by article 9 of the Directive involves three categories of costs: financial costs, environmental and resource costs. However, after 20 years from the WFD enactment, this principle is struggling to be fulfilled and the agricultural sector only recovers a part of operational costs for water services. Several authors agree that applying the FCR will increase the water user payments (Cortignani et al., 2018).

Nowadays, in Italy the actual payment system for water service generates on average a 50% recovery rate. More specifically, according to Massarutto (2015) the rate of recovery is rather diversified along the Italian national territory reaching an average of 50-80% in the North and 20-30% in the South.

This situation has prompted many scholars to identify water pricing strategies able to meet the Directive's objectives and improve efficiency levels in cost recovery.

In this context, Cortignani et al. (2018), by the mean of a mathematical programming model, simulate the impact of replacing the existing pricing system of collective irrigation facilities in Sardinia with several alternatives, at different degree of cost recovery. They have shown that the most efficient tool to increase cost recovery is the volumetric tariff which, however, increases the use of chemicals and the exploitation of groundwater.

Moreover, Giraldo et al. (2014) assessed the efficiency gain achievable with volumetric payment systems that charge farmers for the actual cost of resource delivering. However, the increase in charges generates a very limited total increase in efficiency. Indeed, the authors point out that the net effect could also be negative considering the implementation cost.

Yet, Giannoccaro et al. (2010) have verified, in the Consortium of Reclamation and Irrigation of the Capitanata in Apulia region, that an increase in the current water pricing scheme borne by farmers does not translate into efficiency improvement rather it could negatively affect the labour sector and farmer's income.

In light of these Italian evidence, as regards irrigation water supplied by collective facilities, following FCR by increasing water payments might cause a 'vicious circle' inducing the overuse of complementary water sources i.e. self-supplied irrigation services, significantly affecting low-income users and fail to increase the aggregate economic efficiency (e.g. Dono et al., 2010, Galioto et al., 2013., Portoghese et al., 2021). Indeed, a relevant aspect to consider in the design of irrigation water pricing policies managed by consortia are the potential side-effects they can generate. Actually, in semi-arid regions such as Southern Italy, the conjunctive use of collective facilities and on-farm groundwater require a good coordination in order to avoid the mismanagement of water resource. Under these circumstances, the increase in water pricing incentivizes farmers to overexploit other source of supply such as groundwater, often perceived mistakenly as unlimited and less variable. This condition is exacerbated during water scarcity events increasing the aquifer deterioration and salinization, mostly along coastal area (Dono et al., 2015).

In any case, scientific analyses have always considered uniform pricing policies for all users, assuming a homogeneous demand elasticity. In fact, the elasticity of demand depends on the factor's substitutability (type of crop) and the presence of multiple irrigation services (farm's structure).

The literature provides consistent evidence that irrigators are willing to pay to increase water supply reliability (e.g., Rigby et al., 2010, Mesa-Jurado et al., 2012, Guerrero-Baena et al., 2019, Mirra et al., 2021), justifying their interest in borne higher prices.

Although the effects of climate change are increasingly intense and frequent, limiting access to the resource, aspects relating to the quality and timeliness of the service water supply, as well as the guarantee of administration have not yet been considered in the Italian context with some exceptions (Giannoccaro et al., 2016, 2019).

Within this context the current Ph.D. thesis aims at giving an original contribution to this scientific area of interest. The main aim is to investigate the effect at territorial scale of an alternative water pricing scheme under water scarcity conditions (hydrological drought). The effect was analysed from both an economic and environmental point of

view. In particular, the impact variables considered have been the CBC revenue, the water demand (surface and groundwater) and the farmer's income.
The hypothesis is that a priority rule allowing the implementation of security-differentiated water pricing scheme in drought condition, could enhance economic impact enabling a water reallocation among farms while ensuring a greater degree of cost recovery from collective services.
This mechanism is characterized by a strong element of innovation in the context of irrigation management in Italy, taking into account a relevant aspect for farmers: the reliability of water irrigation service.
Indeed, compared to the national scenario, the alternative mechanism proposed is not limited to increasing the water charge but proposes a differentiated price based on the degree of guarantee of water volume distributed by irrigation collective facilities (i. e. the higher the guarantee the higher the price).

The hypothesis that I intend to verify through this thesis is that a security-differentiated water pricing mechanism can enhance a water reallocation among users translating not only in higher level of water service cost recovery, but also in discouraging farmers from preferring alternative and less monitorable water sources (i.e. self-supplied groundwater), during drought periods.
The novelty of the work lies in designing a water pricing scheme able to reallocate available water resources among farms, thus improve the economic outcomes (i.e. farmer's gross margin and Consortium revenue).
According to Gomez-Limon et al. (2021), the key idea behind this water pricing allocation mechanism is that irrigators cultivating high water-intensive crops (e.g. horticultural crops or orchards) could reduce their vulnerability to drought events by purchasing high-priority rights. In this way, they can face a reduced risk related to the water availability. On the other hand, farmers more willing to assume this risk (e.g. extensive crops cultivators) will prefer low-security priority rights. However, the expected results were not confirmed by simulations carried out in an area of southern Spain.
This is probably a consequence of the fact that the priority resource allocation simulated by the Authors did not truly rely on price-discrimination principle or the different willingness to pay of farmers. They missed differences in demand elasticity as condition

for price-discrimination. In fact, the case study embraced only three broad categories of irrigators, all served by the same collective service.
In this thesis the analysis is carried out in the Capitanata area of Apulia region, in a context where the conjunctive use of collective and self-supplied irrigation services is prominent. Furthermore, ten different farm typologies are considered making the case study more robust and informative.

As regard to the methodology, after an interview-based approach, a positive mathematical programming model was implemented. It is widely used in the ex-ante analysis of water policies, through the simulation of the farmer's behaviour, in the hypothesis that the exogenous variables (water pricing allocation mechanisms and water availability) change. Also from the methodological point of view, the work presents interesting elements of innovation.
The most relevant is to consider, during the modelling stage, the groundwater resource as a limited resource. This information allows to obtain more realistic and robust results in a climate change context where water scarcity events are increasingly frequent and aquifer table level is lowering. However, the pre-existing literature provides empirical application (a recent review is available in Mirra et al. 2021) where groundwater resource is still considered unlimited (Portoghese et al., 2021).

The analysis intends to provide a useful support to reclamation consortia and basin authorities in planning interventions of pricing policies in the light of a higher awareness of the effects produced. Moreover, the objective is to support an adequate design of economic instruments and policies able to mitigate climate change effects and make the agricultural irrigation sector more resilient against drought phenomena.

The water resource in agriculture sector

The availability of water in sufficient quantity and quality is one of the main element for the survival of living species and for several economic activities.

However, the increasing of the world population together with the negative effects of climatic changes, is seriously threatening the world water bodies.

In this regard, the Economic and Social Department of the United Nations, expects the world population to reach between 8,4 / 8,6 billion people by 2030 and between 9,5 and 13,3 billion by 2100. From 2100 on, the numbers are expected to stabilize and begin to decrease. (FAO, 2020).

The FAO estimates that in the last century the global water withdrawal rate grew 1,7 times faster than the population therefore, the concerns about the sustainability of water uses are getting worse as the demand for agricultural, industrial and domestic uses continues to increase.

In addition to the increased demand for water resources, FAO predicts that the climate change will have a significant impact on the water cycle by altering rainfall patterns, affecting the availability and quality of surface and groundwater, agricultural production and associated ecosystems. The increasing variability of rainfall can influence the flow of water in surface systems and the speed of refilling and discharging from the aquifers. In addition, the availability of the water resource, for years considered a renewable resource regardless of its origin and derivation, is now recognized to be varied and limited (Berbel et al., 2007).

In fact, even where water can be considered renewable, if its usage or withdrawal rate overcomes its natural regeneration or when the stock falls below a specific critical threshold, severe risks of lack of self-regeneration and therefore of a definitive extinction can be faced.

In case of fossil waters of deep aquifers instead, there is absolutely no form of reintegration of the water used. That is why this type of source is considered not renewable (Pimentel et al., 1997).

According to the World Water Development Report 2020 (Water and Climate Change) published by ONU, only 3% of terrestrial water is made up by fresh water while 97% is made up by seas and oceans.

Of this fresh water fraction, 79% is stored in polar ice caps and glaciers while 20% is made up by groundwater and only 1% from surface water.

This general situation is made even more complex from climatic characteristics in the Mediterranean Countries where the alternation of rainy and dry seasons makes the availability of resources uneven in time and space (Rigby et al., 2010). Although the water resource is a cross-sector resource in strong competition with all the sectors that use water, (industrial, agricultural, domestic) the most critical situation is undoubtedly the agricultural one for its irrigation practice.

In fact, it is considered the most water absorbing sector recording a percentage of average withdrawals equal to 70% of the total available fresh water.

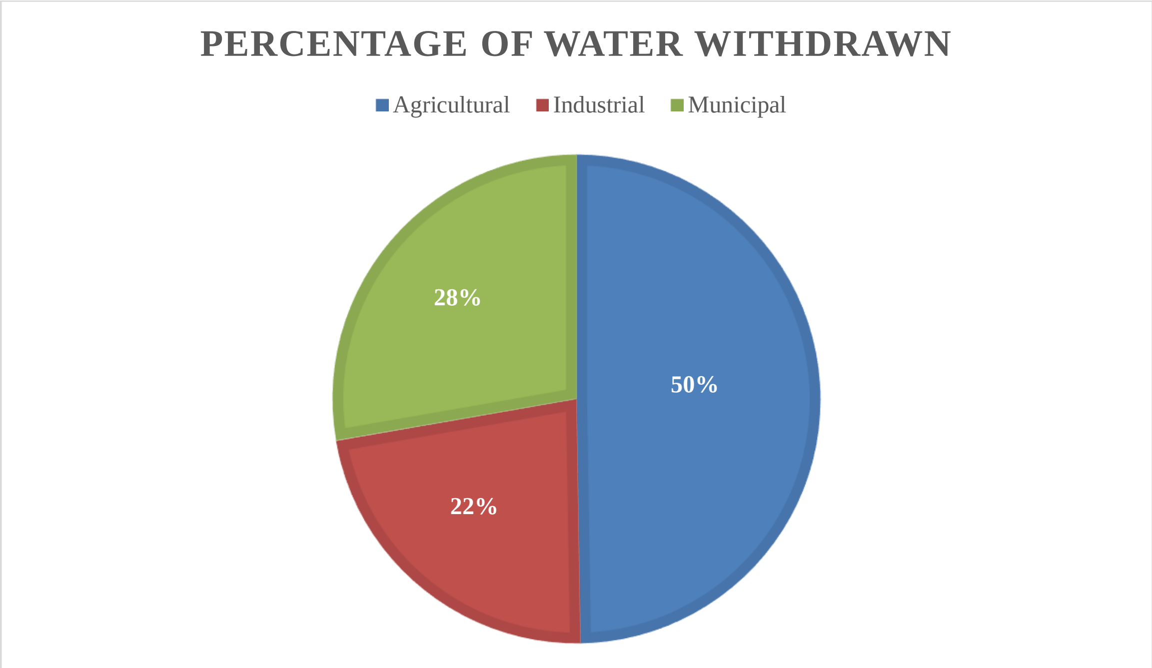
The irrigated agricultural sector is also an expression of the multifunctional character associated with the water resource. If the irrigated agricultural sector and, in particular, its irrigation practice is considered the main responsible of the problems related to the resource, on the other side it plays a role of primary importance in its protection and in the aquatic ecosystems.

Among the problems related to the implementation of the irrigation practice (quality and quantity problems) we can count: the salinization of aquifers and soils, the subsistence and deterioration of the landscape, the reduction of water flows below the minimum vital and the exploitation of renewable water resources. At the same time, irrigated agriculture is a source of several benefits for the environment and for the whole community including rural development, increased competitiveness, development of agricultural activity and related employment activities, protection and conservation of the rural landscape, the hydrogeological balance and the preservation of the biodiversity of natural aquatic ecosystems (Zucaro et al., 2020). Therefore, considering the pressures exerted on the water and the benefits brought about, agriculture plays a role of primary importance in the management and protection of water bodies. It is at the heart of every change process involving natural resources and can be considered the starting sector on which to act to promote an efficient and effective management of the resource.

Irrigation sector in Italy

The agricultural sector represents about 2% of the GDP produced annually in Italy and nearly the 4% of the country employment (OECD, 2020). Among the European countries Italy is considered the most irrigation water user. It is second in terms of irrigated area (excluding protected crops and family gardens) only to Spain with more than 2.4 million hectares. Irrigated areas are mostly located in valley areas and along the coasts. The irrigated areas are characterized by small extensions except for Po, Oristano, Foggia and Pontine valleys. Water consumption in Italy for agricultural purposes is estimated at 15-20 billion m^3 per year. The total amount of water used for irrigation is about 16 billion m^3 per year (ISTAT, 2010). Figure 1 reports the percentage of water consumed by each sector, highlighting the prominent role played by agriculture.

Figure 1 - Percentage of water withdrawn by each sector, AQUASTAT (2018-2022).



As regard to the supply-source, the 66% of total water consumption is derived from natural surface sources, especially in the North, and 6% from reservoirs, widespread in southern and island area. Furthermore, groundwater plays a key role in the Italian water supply scenario. The 28% of the total water consumption in Italy corresponds to groundwater that is mainly used for civil purposes. However, even in the agricultural sector the use of groundwater is remarkable, reaching 20% in some areas. According to the latest census on agriculture (ISTAT, 2010), the greater use of groundwater is associated with small farms size (38% of one hectare surface area use private well). While the larger the farms size, the greater the use of water from the Reclamation and Irrigation Consortia. The high orographic heterogeneity for which the Italian peninsula is characterized translates into a high difference in the Italian irrigation scenario from an infrastructural and organizational point of view. In this context it is possible to divide Italy into three areas. Nord is characterized by a network of reclamation channels used in the irrigation season for the distribution of water (so-called promiscuous network). The management of irrigation is largely collective. Differences are present between the subalpine area with fragmented irrigation and concentrated in the valleys, and the Po Valley and Veneto, extensive and capillary in the lowland territories. In Central Italy the reclamation and irrigation network are on average developed and collective irrigation is present in specialized areas of small and medium size (see Agro Pontino, Agro Romano, Val Tiberina, Tuscan coast). Irrigation has always developed mainly in autonomous way (self-supplied). In the South and in the Islands, reclamation takes place in coastal floodplain areas. After the Second World War, reservoirs and irrigation schemes were created under collective management, but the imbalance between water availability and real requirements still remains. Self-supplied irrigation service is widespread and prevails in some areas such as Puglia and Calabria.

By comparing the equipped area and the irrigated area, the degree of utilization of irrigation infrastructure is on average 71% higher in the eastern Alps (98%) and in the central Apennines (80%) and lower in the south and in the islands (37-50%). The irrigated surface is just over 2 million hectares, of which 80% in Northern Italy (Zucaro, 2011).

Management and allocation of irrigation water resources in Italy

In Italy, the water resource lays in public domain.

In 1994, the issuing of the Galli law no. 35, concerning “the integrated management of the water resource”, a public protection was given to all types of water resources. “All surface and groundwater, if not extracted from the subsoil, are public and need to be safeguarded and used according to criteria of solidarity”.

The access to the resource is regulated by a system of concessions whose competence is transferred from the State to the regions and, in some cases, from the regions to the provinces. More specifically, in agriculture it is possible to identify two main different irrigation water services, namely collective and self-supplied. On the one hand the collective water service is characterized by irrigation distribution networks managed by water user association so-called reclamation and irrigation board (RIB). On the other hand, the self-supply water service (from surface and groundwater sources) is characterized by direct irrigation withdrawals and carried out independently by individual users through wells or direct sockets.

The collective water service

In Italy, the management of the irrigation distribution network is managed by more than 500 irrigation bodies.

They are heterogeneous in size, functions and, from a legal point of view: "irrigation bodies are defined as those which have by statute a territorial competence on the management of water distribution to irrigation users".

The most widespread public institution is the "The reclamation and irrigation board" (Consortia). The consortia, following the latest regulations and the evolution of the use of the soil, act as a point of intersection between different subjects and competences: agriculture, environment and administration of the territory.

Moreover, mountain communities, provinces and land improvement consortia, operate with functions of management of the irrigation network and of the irrigation service to users.

They cooperate with the consortia in the areas not covered by their management.

As already mentioned, the access to the water resources in Italy, is regulated by a system of use concessions.

A part of the costs users have to bear for the use of the resource (as established by the Royal decree T.U. 1775/1933 Art. 35 and from regional laws issued since 1994), they also have to face extra costs such as:

1) Preliminary investigation costs for the authorization request.
2) Costs for the issuing of the concession for derivation and extraction for use.

In many cases the public bodies are authorised to collect in a transitional regime that is with concessions that have expired or are being renewed, some with requests sent over 20 years ago (Zucaro, 2011)

Such concessions give to their holders the right to collect the resource from a specific water body up to a maximum annual volume (full water allotment). The irrigation authorities are given these rights from the corresponding basin authority.

However, the amount of distributed water cannot be guaranteed in advance, but an annual supply plan is drawn up by taking into account the availability of the water resource and of the characteristics of the public systems serving the various irrigation areas.

Furthermore, the climatic condition that define the volume per mc of SAU, have also to be taken into account. The price for the recovery of the service provision costs is also defined on an annual basis. Indeed, the Consortium defines the tariff plan on the basis of the available resource stock at the beginning of the irrigation season.

The types of tariffs adopted by the Reclamation and Irrigation Consortia are quite diversified on the Italian territory.

In general, there are monomial and binomial contributions, with a greater prevalence of monomial tariffs in the northern areas. This element is associated with the presence of an important and concomitant reclamation activities on the territory and multiple use (reclamation and irrigation) of the networks, so it is not necessary to differentiate the management costs from those of the irrigation service. The binomial contribution is more widespread in the southern and island regions and in some realities of the center and the North.

As regard the tariff computation methods, they are distinguished in area-based tariffs, area-based adjusted depending on the type of irrigation system adopted, area-based varying on the type of crop cultivated, volumetric.

Volume-based mechanisms take into account water consumption and can be fixed per unit of consumption or increasing according to volumes. According to the economic literature (Tsur, 2000) this method of charging is indicated as the most efficient and transparent, as well as acceptable to users. Also, in this case the situation is rather heterogeneous in Italy but in general the tariff per euro / hectare irrigated prevails. For further information on the types of contributions spread in Italy see Zucaro et al., 2011.

In case of drought phenomena, the reclamation consortia in Italy adopt the proportional method for the rationing and allocation of the resource.
This method is part of the "symmetric resource allocation mechanism" and is based on egalitarian principles which, however, do not guarantee fairness among users.
In particular, at the beginning of the season, when the availability of the water resource is greatly reduced, the unit volume for each user is reduced in the same quantity regardless of factors as the productivity of the cultivated crops and the risk faced by each farmer. At the same time, regardless of the type of tariff adopted, the consortium increases the value of the tariff for all users.

The self -supply water service

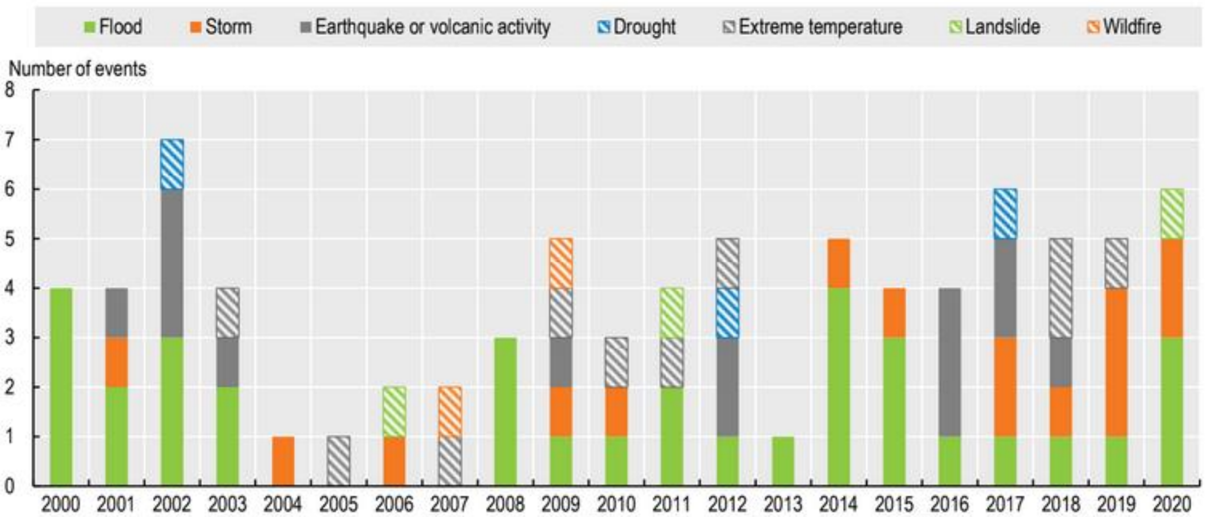
As for the groundwater, the property rights are usually of the State which can grant temporary use concessions to private users.
The State, through its administrations, can exercise a direct role in protecting the quantity and quality of the resource. Therefore, a control of the number of the concessions and on the number of withdrawals is constantly carried on.
In Italy, the management and the protection of the groundwater bodies take place through a "centralized control model". At this regard, an authority with coercive powers is defined with the task of granting concessions, supervising, prescribing and sanctioning violations (in this case, the regions).
Little attention has been paid so far to the cost of creating and maintaining this agency as well as to the costs and the amount of information necessary to establish adequate sanctions and on the difficulty in checking effective compliance with the laws by users (Giannoccaro et al., 2020). A concession-type system, taken to its extreme consequences, can lead to distorted situations regarding the possibility of exercising the right of access to the resource.
In fact, those who already own a concession, are in a privileged position compared to those who have not yet had the opportunity to take advantage of this right.

Moreover, too elaborate forms of control when there are so many points to be observed, a vast territory and little staff available, risk being ineffective or related to complicated and expensive verification systems.

Drought effects on Italian irrigation sector

During the last decades Italy has shown a particular vulnerability to extreme natural events such as earthquakes, floods, landslides, and volcanic eruptions. According to the last OCSE report, around four major disasters occur over the Italian territory each year, reaching sometimes remarkable monetary losses (CRED, 2021). Figure 2 shows the extreme natural hazards events during the twenty years.

Figure 2 - Frequency of disaster events in Italy, 2000-2020. Source: adapted from report OCSE 2021.



The agricultural sector is considered the main user of water resources, making it particularly exposed to environmental and economic risks related to extreme phenomena altering water resource availability and accessibility.

The risks faced by the sector concern both farm-scale losses (decrease in productivity) and public-level losses resulting in higher costs to ensure forms of assistance against natural disasters. The magnitude of the impact is rather diversified according to the area and the scale considered. The most severe impacts are observed in remote rural areas heavily dependent on agricultural activity. Among the various natural disasters, this thesis project focuses on impacts analysis on the agricultural irrigation sector caused by drought becoming more and more intense and frequent over the Italian area.

Drought is a complex phenomenon which is difficult to monitor and define. The climatological academician's community has defined four types of droughts: 1) meteorological drought, 2) hydrological drought, 3) agricultural drought, and 4) socioeconomic drought (Van Loon, 2015). All originate from a deficiency of precipitation or meteorological drought but other types of droughts and impacts cascade from this deficiency.

This phenomenon is also defined as 'the creeping disaster' (DA Wilhite 2000 and Mishra et al., 2010) because it develops slower and often unnoticed and have diverse and indirect consequences. Water scarcity events generate an imbalance between the demand and supply of water resources in each sector. The Italian agricultural sector, during scarce events, has not a priority use in water allocation translating in severe impacts for farmers (Istat, 2019). Even areas less exposed to scarcity events such as Po river basin and pre-alpine lakes, become more affected (Zucaro et al., 2017).

Farmers experience different type of impacts depending on the time frame and the effect magnitude. In the short term, the negative direct impacts results in crop yields decrease, mostly in rain-fed system. Furthermore, hydrological drought (characterized by low water levels in lakes, rivers, reservoirs and groundwater) could translate into in irrigated crop area reduction (OECD, 2016). As argued by Musolino et al., 2017 in the short run drought-induced effect could be smoothed by higher prices (mostly for fruits and vegetables).

Whereas in the long term, the prolonged drought-induced effects could seriously threaten the agricultural sector sustainability. Generally speaking, water scarcity raises operational cost at farm level due to higher water pumping cost. Moreover, water resource reduction result in increase in soil salinity and soil erosion, strongly jeopardize the land's productive capacity (Rossi et al., 2007). Besides the environmental aspects also the efficiency of the Italian water distribution network should be considered. According to Mariani et al. 2020 less than 50% of the water withdrawn at the source reaches the end user, exacerbating water scarcity events.

The context described so far induced italian scholars to analyze the role of collective irrigation (managed by Consortia) in mitigating the effects of climate change. For example, Dono et al 2013 studied the Cuga basin in the north east of Sardinia where the irrigation of the area depends on the presence of a multi-use dam fed by autumn-winter rains. A precipitation reduction and increase of crop water requirements is hypothesized. The results show negative impacts on irrigated area and farmer's income. In this case drought event cause a scarce replenishment of dam leading authors to conclude that improving the management and the infrastructures of collective irrigation could translate in greater strategy of climate change mitigation. Instead of leverage on single farm, as many CAP measures do, an integrated approach at Consortium level is suggested.

Based on the same results, Dono et al., 2014 investigated the effectiveness of the income stabilization tool (IST) provided by the 2014-2020 rural development policy programming. This tool is configured as a solution to compensate for the loss of agricultural income (-30%) in extreme conditions. However, given the expected increased stability of water scarcity, farmers may find it unsuitable, and the tool would remain unused. Again, the authors conclude that an improvement in infrastructure and collective management may represent the most effective strategy. Finally, the Agroscenari project fundend by Ministry of Agricultural, Food and Forestry policies (MiPAAF), through a climatological scenario approach (considering two different decades: 2000-2010 and 2020-2030) investigate the effect of climate change on agricultural crop production.

The results show the raise in groundwater withdrawals associated to climate change effect increasing. The phenomenon was found to be more frequent in the areas less served by the collective service and in general in the Mediterranean areas where groundwater withdrawals are very frequent and water salinization is a growing concern. The results highlight the need to increase the management efficiency of collective systems and to extend their networks to non-equipped areas.

In this context, the present thesis project identifies in an alternative mechanism of water pricing a possible tool for mitigating the effects of climate change. The tool represents a way to improve the management of water resources at the consortium level that aims to recover more sharply the costs related to the provision of the water service provided and at the same time to discourage the exploitation of alternative sources.

WATER POLICIES IN EUROPE

Water policies address problems of scarcity and degradation of water resources. They are placed in the broader context of environmental policies whose first legislation dates back to 1972. In that year, after the first united nations conference on the environment, the European Council highlighted the need of a community environmental policy sustaining economic expansion with the definition of an action program (Voulvoulis and Giakoumis, 2018).

The development of water policies in Europe can be divided into three waves.

In this period, the objectives of water policies, initially focused solely on the qualitative protection of water resources, have undergone a strong evolution, more recently incorporating also objectives of conservation and quantitative protection of water resources. In particular, between 1973 and 1988, the first phase focused on the protection of water for human activities. This phase was characterized by having introduced the use of quality standards for the protection of water bodies (Kuks and Kisslig-Naf, 2013). Directives belonging to this generation protect specific categories of resources used for human activities (e.g.bathing water, fishing water, drinking water). The qualitative status of water resources is defined on the basis of local human uses. For this reason, authors have defined this generation as "human-centred". It involved Water Use Directives that set such standards for drinking water abstractions from surface waters ending in the 1980 Drinking Water Directive (Council Directive 80/778/EEC), bathing waters (Council Directive 76/160/EEC), fish waters (Council Directive 78/659/EEC) and shellfish waters (Council Directive 79/923/EEC) Directives. Moreover, water directives establish emission standards. The aim is to protect the environment and the humans from the absorption of harmful substances, and to prevent environmental dumping or protectionism inside the Common Market. The major emission control component was the Council Directive 76/464/EEC on pollution caused by discharges of certain dangerous chemicals into aquatic ecosystems, a number of ‘daughter’ directives for specific substances and Council Directive 80/68/EEC for discharges into the groundwater. This approach has been criticized for having reduced the complexity of the system to sets of parameters to be respected by limiting a vision of the whole. Lastly, regarding the tools used in the first generation, it is noted that are mainly regulatory, a few being informative.

There is no direct use of economic incentives (e.g. fees and subsidies) and voluntary instruments.
A second phase (1988-1995) concludes the initial phase with more specific measures (e.g. treatment of urban wastewater or limitation of manure disposal) following a command and-control approach and focuses on the limitation of the emissions of certain categories of pollutants. During this period the water eutrophication, resulting from an over-use of nitrates and phosphate, becomes a major issue. This type of pollution has been associated with domestic wastewater and diffuse pollution related to agricultural sector. In this context, Urban Wastewater Treatment and the Nitrates Directive take place both in 1991. Together with the Water Framework Directive they are considered the major water reforms in European Union in recent decades (Albiac et al. 2020).

The Urban Wastewater Treatment Directive defines a series of prescriptive measures. In particular, it imposed to each Member State building depuration plants with secondary treatment plants and tertiary treatment plants (denitrification) in special sensitive areas. More precisely, above 200 billion euros have been invested in wastewater treatment plants. This translated into this considerable decrease of organic matter and of nitrogen and phosphorus emission loads into water bodies, and in a reduced pressure on aquatic ecosystems. Unlike the countries of southern Europe, the countries of central and northern Europe already have purification plants with functioning tertiary treatment (Albiac et al., 2020). However, allowing a considerable potential for expansion of the water supply.

The Nitrate Directive stems to tackle an additional cause of eutrophication: the nitrate pollution caused by agricultural activities. The Directive imposes to each Member State to identify vulnerable zones to nitrate pollution, good farming practices and the establishment of fertilisation limits. The objective is the reduction of nitrate pollution in water bodies and the decrease of greenhouse gas (GHG) emissions associated with excessive nitrogen fertilization and manure surpluses. The introduction of a code of good agricultural practice marks a transition from the informative approach of the first policy generation (e.g. the harmonisation of labelling and packaging of pesticides) and the voluntary instruments adopted in the second generation. Moreover, although in these phases economic instruments are not sill imposed, they are implicitly introduced to allow the measures implementation (subsidies to the farmers to limit manure disposal).

Finally, since 1995, a third phase has begun with the preparation and adoption of the Water Framework Directive. The directive represented an important turning point in the evolution of European water policies. The evolution is observed not only in the objectives that are not limited to qualitative protection but increasingly involve conservation and quantitative protection objectives (considered essential in a context in which the availability of resources is increasingly threatened). Furthermore, the management approach and the instruments utilized has also seen profound innovations. However, the approach to the management of water resources begins to prioritize the good state of ecosystems, passing from a human-centered logic to an eco-centered one. In table 1 the main characteristics of the three reforms waves are reported.

Since the directive represents the reference regulatory context in which this thesis project is placed, more details are provided in the next paragraph.

Table 1 - Main features of Water Directive's wave.

	First wave	**Second wave**	**Third wave (WFD)**
Intervention approach	Immission Limit value	Emission Limit value	Combined approaches
Water target	Bathing water, fish water, groundwater	Surface water, groundwater, drinking water	Water resource
Logic	Human centred	Human centred and partially eco-centred	Eco-centred
Main objectives	Human health preservation, particular water bodies protection, Harmonisation of national legislation, limit emissions of substance non-dilutable	Human health preservation, reduction of eutrophication, reduction of dangerous pesticides trade, industrial discharges reduction, biodiversity protection	Good status for all water, improvement of water allocation, management at a river basin scale
Instrument adopted	Prescriptions and information (national reports, harmonisation of legislation, minimum quality requirements from which emission value are set	Prescriptions, information and self-regulation (action planning and monitoring, detection of sensitive areas, code of good practice, timetable for wastewater treatment)	All instruments, emphasizing economic incentives in the management plan: inventory, programme of measures, introduction of the principle of full cost recovery (FCR)

Implementers	Member states and the EC for some aspects (revision of the emission standard, adoption of 'daughter' directives.)	Member States and the EC/EU	Multi-level (Member states and basin authorities) Multi-sector (environmental, economics and public works).

The Water Framework Directive.

In October 2000, the Water Framework Directive (WFD) established a common framework for water management in Europe, thereby substantially reforming European water legislation. As we observed in the previous paragraph, the directive is the result of long years of evolution in the field of water policy, characterized by strong elements of innovation both in the objectives and in the instruments. The directive, unlike the directives that preceded it, pursues the objective of protecting water resources as a whole (surface water, coastal water, transitional and groundwater). The objectives of the directive can be summarized as follows:

- protect aquatic ecosystems
- promote long-term sustainable use of water resources
- adopt specific pollution control measures (discharges, emissions, losses of toxic substances)
- ensure the gradual reduction of groundwater pollution
- mitigate the effects of floods and droughts

Therefore, the objectives summarized in this way immediately highlight a new approach in the management of water resources. On the one hand, in fact, the goal is to protect the health of aquatic ecosystems and reduce pollution through the use of specific measures, on the other hand, attention is paid to the quantitative aspect (conservation of the resource in the long term and mitigation of the climate change effect as flood and droughts). A further element of innovation lies in the territorial scale of resource management. Indeed, the water resource management bound to the regional administrative limits is replaced by an integrated management at the basin level. The Directive requires member states to identify river basins and assign them to basin districts (defined as the main unit for the management of the basins). In addition, member states identify the competent national authority (basin authority) which ensures the implementation of the rules provided by the Directive in each district.

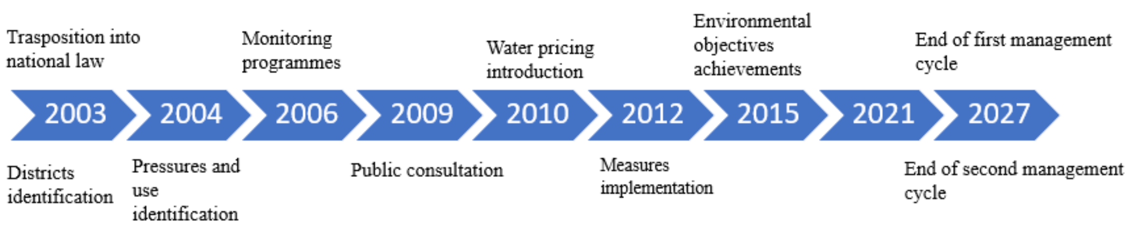
Each member state draws up a river basin management plan for each district in the area. The latter can be supplemented by more detailed management programs and plans for sub-basins, sectors, or categories of water.

The implementation process

The complexity of the issue has resulted in a very gradual implementation process marked by precise phases. To begin with, the directive provides for a careful examination of the environmental context and an assessment of impacts and pressures, identifying the most water- consuming and water-polluting sectors. Furthermore, the evaluation of the costs and benefits deriving from the use of the water resource is carried out. At this point it is possible to establish the objectives to be achieved in terms of qualitative and quantitative protection of the resource and to draw up an action plan containing the measures to be implemented to achieve the pre-established objectives. Finally, the action plan, constantly monitored to verify the effectiveness of the designed measures, can be implemented. The results obtained must be made public in order to ensure an informed and participatory decision-making process that allows for a possible revision of the plans.

The programme for implementing the Directive is expected to run for 25 years:

Figure 3 - Implementation process.



River Basin Management Plans should be published within nine years of the Directive's entry into force, be reviewed and updated within fifteen years and every six years thereafter. The monitoring of the waters in each river basin district in order to assess the chemical, ecological and availability status has been foreseen since 2006. Instead, since 2010, member states have to apply water pricing schemes incentivizing an efficient water resource use and guaranteeing the recovery of the costs of water services including environmental and resource costs. The program of measures is to be fully implemented in 2012. In 2015, the environmental objectives should have been achieved. Finally, in 2021 and 2027 respectively, the first and second management cycles end up.

The role of economic analysis in WFD applied to the agricultural sector

The Water Framework Directive represents the first experience in Community legislation on environmental issues in which economic analysis plays a predominant role. Roughly speaking, the fields of application of economic analysis concern two aspects:

- Water full cost recovery evaluation
- Cost-effectiveness assessment of the basin plans measure.

Water full cost-recovery evaluation:

Article 9 of the directive provides for the identification of pricing policies that encourage a rational use of water resources, as well as the full cost recovery by different sectors including agriculture. The concept of full cost is based on the more general concept of total economic value. The hypothesis is that the price of water defined by market transactions or imposed by public water management systems does not reflect the real value of the water resource. These prices reflect only a part of the total economic value of water which, as Pearce and Turner defined in 1991, is composed of real use value, option value and existence value. Real use value corresponds to the benefit derived from the actual use of the resource. The option value is associated with the benefits of potential uses of the resource by individuals and future generations. Finally, the existence value is the value attributed to the resource regardless of its use. The determination of these types of values depends on the renewable characteristics of the water bodies, the institutional structure and the system of values concerning the use of natural resources in each state and above all on the uses of the resource.

In agriculture, water uses concern two categories: the use of water for irrigation and water pollution due to the use of fertilizers and disposal of livestock waste. As far as irrigation is concerned, agriculture represents the most consuming sector (between 50 and 90% of the total availability).

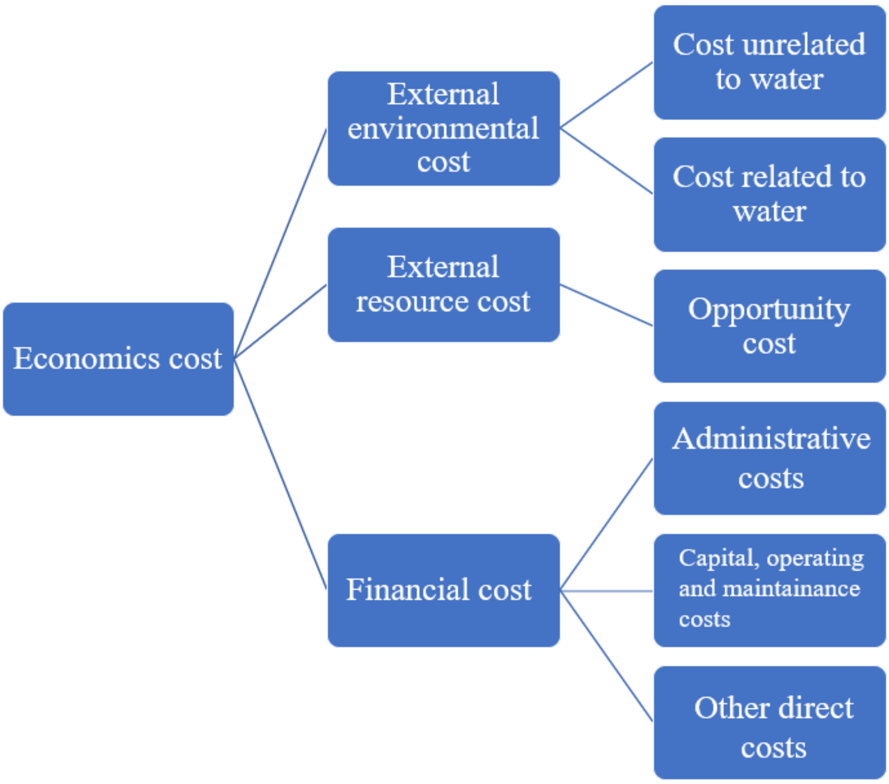
The agricultural sector's water uses if often the cause of conflict with other industries because of the high quantity of water needed, in addition to the fact that this water is needed during the driest season of the year.

With regard to pollution, the use of water as a receptor of pollutants is practiced by many sectors. However, the agricultural sector is distinguished by the quantities of pollutants released (nitrogen in particular) and because it produces non-point source pollution.

In this context, the water value assessment and the definition of full cost recovery for water services is not exempts from difficulties.

The full cost recovery as advocated by the Water Framework Directive in article 9, includes the financial, environmental and resource costs. Figure 4 briefly describes the full cost components.

Figure 4 - Implementation process.



The financial costs cover the implementation of irrigation infrastructures and the management of water services. These costs include operating costs, depreciation costs and the costs of using capital. *Resource costs* are associated with lost income opportunities related to potential alternative uses.

Environmental costs reflect the environmental damage caused by the use of water resources. However, twenty years after the Water Framework Directive was issued, the implementation of economic instruments and the level of recovery of environmental and resource costs are still poorly harmonized between the countries of the European Union. Basically, there is an inherent difficulty in defining and quantifying the aforementioned costs (Berbel , 2019).

As regards the opportunity cost, the main difficulty lies in knowing the water demand function of each sector using water. In this way it would be possible to calculate the marginal variation of the opportunity cost in relation to the quantity of water removed from the sector. However, there are numerous aspects related to the characteristics of the water resource that prevent an easy definition of the demand function such as capital indivisibility, increasing unit water costs and temporal and locational variations in costs (Warford, 1987).

As regards the assessment of environmental costs, the methods used coincide with those proposed by the traditional literature on environmental assessment:

- market methods: used for goods and services for which a market exists
- cost base valuation methods: based on the assumption that the cost of prevention measures approximates the external cost
- revealed preference methods: based on agent behavior (travel cost, hedonic price)
- stated preference method: based on the willingness to pay detected through interviews (contingent valuation)
- value transfer: based on the use of information on costs and benefits deriving from areas other than the one being valued

The use of such methodologies on a large scale and in a systematic way is still under discussion. Indeed, they are characterized by high application costs and doubtful reliability. It is also important to consider that the use of water in agriculture produces not only negative but also positive effects. This aspect broadens the range of effects to be taken into account and complicates the calculation methods.

Cost-effectiveness assessment of the basin plans measure

The second area of intervention of the economic analysis is in the economic evaluation of the measures’ effects. This activity plays an important role in the ex-ante evaluation of programs. Evaluation implies explicit predictions about actors’ behaviour. The assessment can support policy makers in identifying appropriate intervention strategies or postpone / cancel it. In this context, the study of farmers' behaviour in response to water pricing policies is of remarkable importance. Indeed, several authors identify water pricing as an essential tool to encourage water saving in agriculture.

The behaviour of the actors can be represented through different tools such as: experts’ or stakeholders’ interviews, literature analysis, development of statistical or economic models. However, the most commonly used tools concern econometric models and behavioural models of mathematical programming. The former mainly applied to the analysis of water use in the civil and industrial sector. The latter considered to be more suitable for capturing of the agricultural system complexity and the behaviour of farmers.

ECONOMIC PRINCIPLE AND INSTRUMENTS OF WATER ALLOCATION IN WATER SCARCITY CONDITION

Economics is “the science which studies human behaviour as a relationship between ends and scarce means which have alternative use” (Robbins, 1983). Scarce resources are by definition available in limited quantities compared to their demand justifying the application of economics principle to their allocation among different users. Water resources, and natural capital in general, as ‘scarce means’ and not reproducible without limits, represent an economic resource. As for any resource, the goal is to ensure its efficient use.

However, water is a complex economic good involved both in economic activities (e.g., as input in several production processes such as irrigation and industry) and in social and environmental ones (e.g., water-related ecosystems and drinking and sanitary water).

For this reason, a successful water policy, aiming at leading the water-related activities to a “socially optimal outcome” has to consider both the economic efficiency and the distributional equity. In this context, policymakers should design a water policy identifying a trade-off between efficiency and equity objectives (Fabiani, 2014).

Water Markets

The economic instruments rarely allow the simultaneous fulfillment of the two objectives. Furthermore, ensuring an appropriate allocation of resources becomes an ambitious goal in conditions of water scarcity. According to the neo-classical economic theory the best instrument to allocate economic (scarce) good, including water resources, among their alternative uses is the market. More specifically, the First Theorem of Welfare Economics states that in the presence of competitive markets for all commodities considered private goods, the economic equilibrium achieved is efficient (Gravelle 2004). Markets are based on decentralized price-mechanism allowing the achievement of allocative efficiency, well-known as Pareto efficiency.

A pareto-efficient market equilibrium is considered a *first-best* allocative solution; in this case it is not possible to improve the well-being (utility) of a subject, without worsening the well-being of the other subjects. Markets generate a system of economic incentives to allocate water to higher values uses by the means of trade operations between sellers and buyers, until the achievement of the equilibrium price where further gains from markets are depleted.

More specifically, markets lead to an equilibrium where the marginal value of all water users is equal to the equilibrium price ensuring the maximization of their net benefit. Whitin this mechanism, the equilibrium price always reflects the full opportunity cost of water resource.

In this context, economic water literature has identified competitive water markets as the most efficient water allocation instrument to face water shortage situations (drought).

However, this mechanism does not take into account the equity distribution of the resource. Indeed, Pareto-efficient allocation could be rather inequitable, resulting far from guaranteeing the maximization of the function of social welfare during water scarcity period (Poddar 2014).

Another critical issue related to market mechanisms concerns the nature of the water resource. This mechanism shows high performance in case of allocation of private goods (category of rival and excludable economic goods). However, irrigation water shows common pool resource characteristics (rival in consumption and not excludable) leading to a several number of market failures hampering the achievement of an efficient equilibrium for the resource and for society as a whole.

Indeed, water is involved in several public activities that have not a market price highlighting their relative scarcity. For this reason, when irrigation water is exchanged through market the equilibrium reached is not efficient and price does not reflect the actual opportunity cost of the resource. The benefit and cost function omitted information.

According to Albiac et al. 2020, it is possible to identify four main instruments to cope with market externalities created by the common pool and public good characteristics of water.

1. Command and control by the water authority
   instrument used: Regulations and sanctions for non-compliance.
2. “Pigou solution”

instrument used: Taxation of water extractions. It corresponds to the water pricing approach as prioritized by European Water Framework Directive (EC, 2000).

3. “Coase solution”

   instrument used: Market and trading based on the previous privatisation of the resource. It is also known as market approach mechanism widespread in Australia (Hart, 2016).

4. “Ostrom solution”

   instrument used: collective action as crossroad between the strictly state management of resources and strictly private management. Ostrom believed that coercive government rules cannot be a solution because they lack legitimacy and knowledge of local conditions (Ostrom 1990).

Centralized allocation rules: proportional method vs priority.

In order to overcome the side-effect related to the market decentralized price mechanism (often resulting in “unfair” resource distribution”) the revision of centralized allocation rules could represent a good alternative for improving resource allocation in irrigation sector during drought situation. These allocation rules are fixed by the state that could set up water rights regimes in order to guarantee the best water resource allocation between users in water scarcity conditions.

As argued by Gomez-Limon et al., among these allocation rules it is possible identify two main approaches to rationing irrigation water allocations: the symmetric and the asymmetric methods.

According to Alarcon et al.,(2014) and Goetz et al., (2017) the most widespread method in Europe is the proportional rationing method. This method, as for the other method belonging to the symmetric category, is based on the axiom of “equal treatment of equals”. More specifically, during drought events, farmers receive an amount of water proportional to their water rights, guaranteeing that total demand equals total supply. The proportional rule is so widespread because it enjoys a very high degree of acceptability among stakeholders. Basically, it is considered a fair instrument to manage water scarcity and rather easy to implement.

However, as reported by Martinez and Esteban 2014, this method does not lead to an economic efficient water allocation. This is explained by the fact that farmers, more specifically irrigators, are characterized by rather different features such as input factors endowment, environmental conditions, farm size, risk aversion, other psychological attitudes. All of these features, translate into a different decision- making process determining a huge variability in irrigated crop pattern and water productivity. For this reason, the proportional method only apparently turns out to be a fair instrument. In fact, it has very different negative impacts among farmers failing to minimize the aggregate losses hindering from water scarcity.

As regards to the priority rule, the mechanism is based on a hierarchy depending on the priority class to which each irrigators belong. The higher the degree of priority, the sooner the demand for water resources will be met. The remaining resource allocated to the following rights holders according to a criterion of decreasing priority order (Gómez-Limón et al., 2020).

According to Freebairn and Quiggin 2006 and Lefebvre et al., 2012 the implementation of priority rights system within the irrigation sector enhance more efficient water use and risk-sharing, translating into a useful adaptation strategy during the water scarcity periods affecting the agricultural sector.

This allocation mechanism, so-called security-differentiated water rights, take into the account the farms heterogeneity in terms of irrigated crop pattern, water requirements and risk aversion. Indeed, following this procedure, the irrigators cultivating high-intensive crops (i.g. horticultural crops or orchards) could reduce their vulnerability to drought events by purchasing high-priority rights. In this way, they can face a reduced risk related to the water availability. On the other hand, farmers more willing to assume this risk (e.g. extensive crops cultivators) will prefer low-security priority rights.

Moreover, this mechanism translate into improved economic efficiency in the long-term because higher priority right holders increase the degree of specialization in higher value-added systems.

However, the setting-up of this mechanism is not so frequent because of high transaction cost necessary to guarantee the designing of efficient water rights. Moreover, rights holders are treated differently, and this decrease the level of acceptability from social and political point of view.

Priority allocation rules are functioning in the Western United States and in the Australian states of Victoria and New South Wales. In the first case they follow priority determined by seniority (full priority) whereas the Australian case is based on two priority classes (i.e., ‘high-security access’ and ‘general-security access’ entitlements). In conclusion, according to Gomez-Limon et al., 2020, both cases represent an international experience to learn from in order to improve agricultural water management.

Price discrimination as a strategy to allocate water resource

Price discrimination is a pricing strategy where identical or largely similar goods or services are sold at different prices by the same provider in monopoly markets. The key idea behind this strategy is that a company practicing different pricing for the same good to different consumers or group of consumers could obtain greater profits than those obtained by practicing a uniform price. All methods of price discrimination can be considered attempts to minimize the effect on marginal revenues that derives from the sales expansion.

The attempt is to make only one customer pay a lower price without simultaneously applying the discount to all consumers.

The conditions that allow the adoption of this strategy are the following:

- the enterprise must have market power
- The enteprise must know, or be able to infer, the consumers’ willingness to pay for each unit of good.
- The company must be able to prevent or limit the resale of the good by customers paying a lower price than those who pay a higher price (arbitrage). If the group that was charged a lower price can resell to the other group at a lower price than the monopolist none of the second group would buy directly from the monopolist.

Generally speaking, there are three different price discrimination strategies that can be adopted:

1) First degree or custom price
2) Second degree or menu pricing
3) Third degree or group pricing

In order to adequately answer the research question of this thesis project we will focus on the third strategy. The third type strategy foresees that the monopolist does not have enough information to know the willingness to pay of each consumer. However, he knows that there are groups of consumers with a different willingness to pay and a different price elasticity of demand (group pricing). A typical example of a third-degree strategy is that of airlines offering different tariffs for the same flight. Different prices are charged to different groups while a uniform price is adopted within the same group (linear price).

In this thesis the economic conditions for the third-type strategy are assumed. As argued by Mirra et al. 2021, irrigators are willing to pay to increase water supply reliability. According to economic theory, the farm typologies having a major degree of factor's substitutability (rain-fed alternative crop and multiple irrigation service) are supposed to have a more elastic water price demand. Whereas, farm typologies less flexible (orchards cultivators or single irrigation water service) will show a higher inelasticity.

In this way the Consorzio di Bonifica ed Irrigazione della Capitanata (CBC) could discriminate the water price service between the different farmers group.

The water service offered by CBC is not completely homogeneous (presence of self-supplied service managed by regions), however the increasing return of scale of collective water supply leads the CBC associable to a natural monopolist (Cortignani, 2008).

Therefore, we hypothesize in this work that the Consortium can also benefit from discriminating the price of water resources making the water service cost recovery more efficient, especially in conditions of scarcity when losses are higher.

CASE STUDY

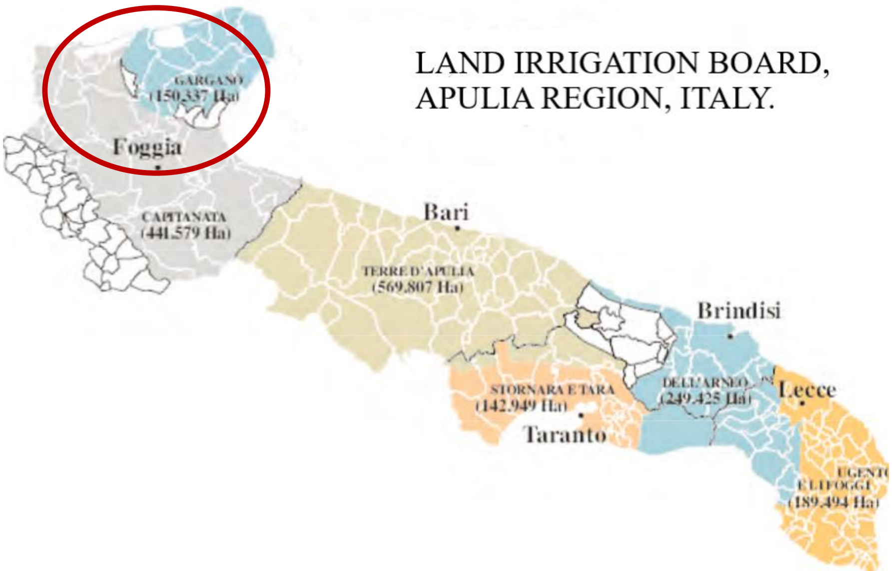
Capitanata area description and Consorzio structural characteristics

The widespread use of irrigation practice and the cultivation of high-value crops make irrigation a key factor for Apulian agriculture. Indeed, the production value of irrigated crops represents more than two thirds of the whole agricultural crop production.

The Apulian land area is 1,933,652 hectares of which 90% (1,743,591 hectares) falls within the boundaries of the 6 Apulian Reclamation Consortia (Gargano, Capitanata, Terre d'Apulia, Stornara e Tara, Dell'Arneo, Ugento Lì Foggi). In Apulia, a total of 231,046 hectares are equipped with consortium irrigation networks; 60% of this surface falls within the boundaries of the reclamation and Irrigation Board of Capitanata (CBC) which corresponds to the study area where the current research is carried out.

The CBC develops within the administrative limits of the province of Foggia, including most of the Tavoliere delle Puglie flat area and a lesser extent of the sub-Daunian Apennines. The geographical boundaries, as defined by the consortium statute, are represented by the mouth of the Saccione river to the north-west, the Adriatic and the Gargano promontory to the north-east, the Ofanto river to the south-east and the Dauno sub-Apennines to the SouthWest.

Figure 5 - Maps of Apulian Irrigation and Recalamation Board (RIB).



Regarding the climate, the Capitanata is characterized by a temperate climate typical of the Mediterranean area. Indeed, the proximity to the sea and the low altitude translate into average annual temperatures between 17 and 18 Celsius degrees. The coldest month is January with average temperatures between 6 and 10 degrees. On the other hand, the month in which the highest temperatures are recorded is August with averages between 25 and 27 degrees (ISTAT, 2019). Rainfall is typical of a semi-arid area with a range of 600-1200 mm / year in ordinary years and a minimum of 300 mm / year in drought years. A decrease in these values is observed in the Tavoliere area while rainfall increases in the mountainous one. The rains are concentrated in autumn and winter, while in the summer season the number of rainy days is small with a minimum peak in August.

The Capitanata area represents an intensive agricultural area and is the largest irrigated area of Puglia (Southern Italy). The agricultural area is approximately 500,000 ha in which wheat, olives, vegetables, and grapes are widely cultivated. The annual irrigation requirement is satisfied through both a collective network managed by the local irrigation board and on-farm individual groundwater pumping systems. The CBC, a public body ruled by farmers representatives, manage the distribution of surface water in the irrigation district. Precisely, it brings together 39 municipalities reaching a total extension of 441,579 ha of the whole agricultural area. The irrigation network is available approximately on 150,000 ha, but only 126,000 ha are effectively supplied.

In the Capitanata area it has allowed the realization of the water schemes the local irrigated agriculture currently relies on:

- Fortore scheme (Puglia and Molise)
- Ofanto scheme (Campania, Basilicata, Puglia)
- Carapelle scheme (Puglia)

Water scheme Fortore and Ofanto are defined interregional schemes. Actually, the hydro-morphological characteristics of the area does not allow the fulfilment of industrial, agricultural and urban demand. Due to the interregional schemes, it is possible to satisfy the water needs of Puglia and the neighbouring regions (Basilicata and Molise).

Fortore Scheme

Fortore scheme covers the irrigation area of Fortore catchment (CBC, Puglia) and that of Larinese (Molise). The Apulian side is located in the central northern part of the province of Foggia, it covers a total area of 155,000 hectares. The water supply sources are diverted from Occhito dam, on the Fortore river, and the Capaccio dam on the Celone river. The estimated capacity for the Occhito reservoir amounts to 250 Mm^3. However, the scheme is not fully functional, therefore the actual average availability recorded in recent years is equivalent to 150 Mm^3. For the irrigation needs of Puglia and Molise, the Fortore scheme makes available 96 and 1 Mm^3 respectively. The Fortore scheme is divided into two different banks: North Fortore and South Fortore. In North Fortore, 35 loading and compensation tanks distribute the water by gravity to 5 irrigation districts for a total of 40,000 hectares. Instead, in the South Fortore 9 irrigation districts were served by gravity for a total of 65,000 hectares.

Considering the total equipped area (102,500 hectares), the irrigation requirement is currently 200 Mm^3, for drinking purpose 60 Mm^3 and 5 Mm^3 for industries. Therefore, a deficit of 115 million cubic meters is registered and an increase of up to 200 million cubic meters is expected. In this scenario, it is expected that the entry into operation of the reservoir on the Celone stream with 16 Mm^3 and the construction of the future cross of the Vulgano with another 6.5 Mm^3 will only mitigate the water demand excess compared to the supply water. In order to fill the deficit, the general water plan provided the building of the following water infrastructure:

- Piano dei Limiti dam, 40 Mm^3 (executive project awaiting financing);
- Triolo stream reservoir, 8,4 Mm^3 (performs storage and regulation functions through the Tavoliere open-air supply channel.
- use of wastewater from the main municipalities
- Biferno, Trigno and Sangro rivers derivations through the interconnection of the waterways with the existing dams in order to ensure the reservoir coverage.

Ofanto Scheme

The Cassa per il Mezzogiorno in 1955, through a master plan, provided for the construction of two storage reservoirs for the Sinistra Ofanto scheme (Rendina e Capacciotti) and two reservoirs of storage and modulation (Osento e Atella). Finally, a diversion crossroads on the river (in S. Venere) to allow to derive the winter water flows for the Capacciotti and Rendina reservoirs and the natural summer ones of the river. The resources available for the CBC Sinistra Ofanto district have been estimated as 76 Mm^3 with an endowment of 2000 m^3 / ha for a total irrigable area of 38,000 hectares. Currently, the data on the actual availability for the entire water scheme are conditioned by the state in which some of the main works of the scheme are located. Of the total area served (38,000 hectares) that actually irrigated is 28,000 hectares and exceeds the expected assignment (2000 m^3 / ha).

Carapelle Scheme

The Carapelle scheme, located in the central-southern part of the Tavoliere, has not yet been realized. The sources of supply are the Carapelle and Cervaro streams and their tributaries. The works that were planned to be carried out are represented by the reservoir on the Carapelle, and by the crossroads of derivation on the Cervaro stream. These works should allow a water storage of about 85 Mm^3 to be allocated over 50% to irrigation and the remainder to industries. In addition to the water resource managed by the CBC, in the same area there is a considerable presence of private wells through which farms draw directly from private wells. There are an estimated 45,000 (which includes both those regularly denounced and the abusers).

Consorzio water resource management

Originally, reclamation irrigation board were created to recover land for agriculture and to ensure the health safety of swampy areas. Later in the 60s to the main function of reclamation, the management and distribution of surface water resources to agriculture was added. As pointed out in the previous paragraph, the CBC is mainly divided into two large districts: Fortore scheme and Ofanto scheme.

The distribution system of the Fortore scheme consists of 37 storage and compensation tanks with a capacity ranging from 20,000 to 100,000 m^3. The network covers 6000 km and consists of concrete pipes piped under pressure. The irrigation area is divided into 17 irrigation sub-systems. The unit resource allocation per hectare corresponds to 2050 m^3/ha which can be distributed through on-demand delivery service. According to the CBC's regulations, the irrigation season begins on March 1st and ends on November 30th.

In this area the most common farm irrigation systems are the localized low pressure drip irrigation and the sprinkler methods.

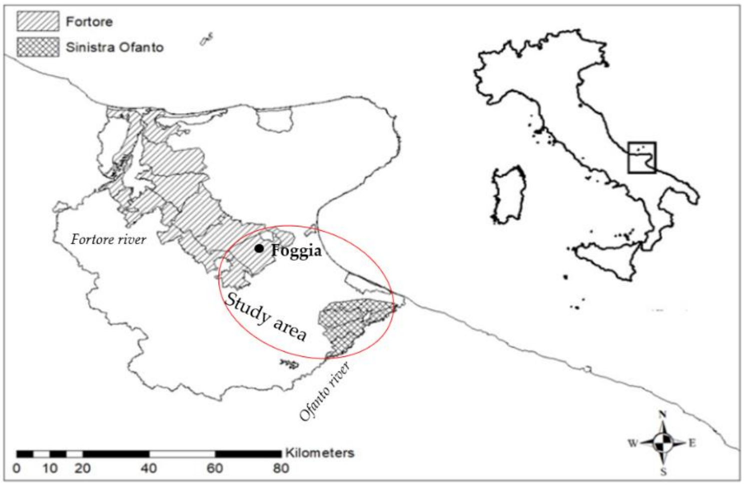
The Sinistra Ofanto irrigation scheme consists of 10 storage tanks of capacity comprised between 20,000 and 40,000 m^3. In addition, there are 3 pumping plants serving an area of 13,650 hectares. The remaining surface (24,737 ha) is served exclusively for gravity. The area consists of 16 irrigations sub-systems. The distribution network has been designed assuming an allotment of 2050 m^3/ha and a delivery group for every 7 ha for a total of 5400 delivery points. In this area, the imbalance between supply and demand for water resources is more prominent. In fact, many hectares of olive trees planned during the design phase of irrigation infrastructures, have been converted to vineyards hectares. This resulted in a demand increase during the peak period (July-August). In this context, the consortium reserves the right to alternate the demand delivery service to the turned one. The shift period has an average duration of three days during which part of the sectors belonging to the same district are closed.

As regards the recovery of financial costs, the CBC adopts a binary tariff. Volumetric tariff is determined on the basis of the costs incurred by the consortium to distribute pressurized water in the network. This tariff consists of two components: 1) a yearly fixed cost charged by farms falling within the administrative area (60 €/ha although the resource is not used) 2) a volumetric three-tier water tariff scheme based on irrigation water use (0.12 €/m^3 with a unit volume under 2050 m^3/ha; 0.18 €/m^3 with a unit volume ranging from 2051 to 3000 m^3/ha; 0.24 €/m^3 for further amounts). The volume measurement is carried out through volumetric meters. Moreover, the volumes are quantified according to the water rights that are not transferable. According to the CBC irrigation census, the 24% of CBC revenue derives from the fixed component related to the farm irrigated area, whereas the remaining 76% depends on the applied volumetric block tariff. The management of water resources in drought conditions consist of the assignment of fixed quotas per hectare. In this case, withdrawals in excess of the limits agreed at the beginning of the irrigation season are not allowed. Moreover, of the total water volume assigned, calculated for the entire irrigation season, no more than 50% can be used in the peak period, between June 15 and August 15.

Study area

The study area selected as a case study of this research project falls within the administered area of the CBC and precisely in the area shown in figure 6. As can be seen, it is bordered to the north by the Fortore river and to the south by the Ofanto river.

Figure 6 - Study area. Source: adapted from permission of Giannoccaro et al., 2019.



The choice of this study area lies in the interesting management of the water resource. In this area the joint use of surface and groundwater water for irrigation purposes is widespread. Actually, the area is characterized by a significant presence of private wells used by farmers to withdraw directly from the water table.

In this context, any change in the consortium's tariff policy could have effects on the exploitation of groundwater reserves. For these reasons, this study area is particularly suitable in order to answer the research question of this thesis project. Overall annual irrigated land accounts for 121,266 ha, of which almost 50% is mostly supplied by collective irrigation services. The remainder is irrigated directly by self-supplied services, normally from groundwater resources. In several cases, farmers rely on both types of services. In addition to these services, there are the distribution networks of the Arif (Regional Agency for Irrigation and Forestry activities) and the municipal networks for the distribution of water supplied by tertiary sector systems for irrigation reuse. Moreover, there is no shortage of direct supplies from surface waterways and, even if to a limited extent, there is supply from unconventional sources through the use of refined wastewater. However, the self-supply irrigation service from groundwater represents the most important component of Apulian irrigation (more than 60% of the average volume used for irrigation).

Therefore, irrigation services can be identified in two main types: collective irrigation service and self-supplied. In the first, water supply is managed by CBC providing water under pressure (either in rotation or on demand) at each farm plot through the irrigation infrastructures of pipelines. The water source is generally diverted from river basins which are regulated by means of dam systems. As mentioned in the previous paragraph, the CBC is in charge of defining water rights for irrigation, i.e., how much water farmers can seasonally benefit from and when they can do so. They also establish the water pricing policy.

By contrast, the self-supply water service is self-organized by water users. Indeed, after obtaining a public permit or a license to drill a well, end users pay for all the financial costs of the water supply. In this case the service is considered self-organized. In some European member States, the access to water source, besides the fees for licensing, can be charged with environmental taxes. In the case of self-supplied services based on groundwater resources, a common issue is the aquifer overexploitation. Actually, in areas where groundwater is the main source of fresh water, the withdrawal flows exceed the natural recharge flow rates causing the continuous absorption of the groundwater, the depletion of wells, an increase in the costs of extraction and a serious intrusion of sea water in coastal aquifers (PTA, Puglia region). Actually, public authorities face several problems to ensure the control and monitoring of groundwater use that translate into issues just mentioned.

Sample

A sample dataset of 75 observations was obtained through a face-to-face survey of farmers carried out in 2019 by trained interviewers. A snowball sampling procedure was followed in order to align sampled cases as much as possible to irrigated crop pattern, annual water used and irrigation water service type in the study area. Despite the size of the sample, a higher proportion of farmland area of the study area was sampled, namely 4861 ha of total utilized agricultural area with 2017 ha actually irrigated. As a whole the sample showed a good representativeness of irrigated crops (Table 2), by water service type as well (Table 3).

Table 2 - Sample representativeness.

	Sample		**Study area**	
Total farmland (ha)	4,861		237,951	
Irrigated land (ha)	2,017		66,536	
Yearly average irrigation volume (m^3/ha)	2,386		2,740	
Irrigated crops land:	**(ha)**	**%**	**(ha)**	**%**
Tomato	363	18	13,442	20
Vineyards	323	16	22,312	33
Orchards	82	5	3,396	5
Vegetables	741	37	11,331	17
Permanent vegetables	176	8	1,577	2
Olive grove	150	7	13,089	20
Others	182	9	1,389	3
Total	**2,017**	**100**	**66,536**	**100**

Table 3- Crop pattern by water service.

Water service	**Collective**		**Self-supplied**		**Multiple service**	
N	19		37		13	
SAU (ha)	Total	Irrigated	Total	Irrigated	Total	Irrigated
Total	**1,149**	**565.17**	**1,729.09**	**735.89**	**1.983**	**716.50**
Cereals	501.7	56.7	862.78	26.9	1253	46
Legumes	142.1	-	185.51	-	100.5	12
Tomato processing	74.31	74.31	50	50	259	259
Fresh tomatoes	-	-	3.5	3.5	-	-
Potatoes	-	-	-	-	3	3
Melon	-	-	-	-	5	5
Cabbage	50	50	156	156	101	101
Beet	238	238	75	75		
Lettuce	-	-	-	-	6	6
Fennel	-	-	2	2	104	104
Artichoke	-	-	30	30	-	-
Asparagus	35.66	35.66	50	50	61	61
Secular Olive grove	5.5	4.5	3.5	3.5	-	-
Olive grove	4.2	4.2	69	58	28.5	18.5
Intensive olive	28.5	28.5	14.99	14.99	22.5	22.5
Trellised vineyards	3	3	16,5	16,5	30	30
Tent vineyards	32.8	32.8	137.01	137.01	10.5	10.5
Table vineyards	33.5	33.5	18.8	18.8	-	-
Orchard fruits	4	4	62	62	-	-
Others	2.7		61.5	32.5	76	76

A structured questionnaire was administrated to farmers in order to gather farm cropping patterns, structural and socio-demographic farmer characteristics, irrigation water use and water resource management. The total number of observations for irrigation was 69.

Table 4 shows the main sample statistics.

The variables analysed are divided into three categories: farmer's characteristics, farm's characteristics, water.

The average age of sampled farmers is almost high, reaching 50.3 years. This data confirms the phenomenon of the ageing of the Italian agricultural sector highlighted by many scholars. Furthermore, only 10% of the sample is female and on average 58.57% of the interviewees declare to the high school diploma, as education level. Finally, it is noted that 46% of farmers access agricultural credit, and 14% have adopted irrigation innovations during the last five years (adoption of computerized irrigation management systems). According to the literature, these variables are considered proxies of dynamism and high managerial skills.

With regard to the farm's characteristics, on average the total land owned corresponds to 43.83 hectares, suggesting large dimension of farms sampled. However, the standard deviation suggests that sample, although small, is highly heterogeneous. The average values relating to the managed irrigated land confirm the irrigation vocation of the sampled farms. Actually, 50% of managed land is irrigated.

Finally, considering the water resource, the analysis of the variables shows that on average farms have just one irrigation service, namely 27% collective service and 53% self-supplied. The remainder 20% represents farms adopting both kind of services.

Finally, the sample shows, on average, little attention to the internal accounting of the water resource. Only 16% have installed volumetric meter devices.

Furthermore, the questionnaire aimed at investigating farmers' perceptions of aquifer's deteriorations. Actually, with regard to the self-supplied water service, farmers were asked if they had encountered problems with the quantity or quality (salinity) of water. Although historically considered more reliable, the increase in anthropogenic pressure on water resources and the climate change effects highlight the weaknesses of the service. It turned out that 44% of farmers indicated quantity problems and only 0.04 quality saltrelated issues. Finally, further information was collected through the survey for the model construction. More details have been provided in the following paragraphs.

Table 4 Sample's descriptive statistics.

Sample	N	69
Farmer's characteristics	*Mean*	*SD*
Age	50.18	10.95
Education	4	0.64
Credit access	0.46	0.50
Innovation	0.14	0.35
Farm's characteristics		
Total land owned	43.83	58.29
Managed land	61.33	75.81
Managed irrigated land	29.68	44.29
Managed irrigated rent land	11.12	37.88
Water		
Collective service	0.27	0.45
Self-supplied service	0.53	0.50
Multiple-service service	0.20	0.39
On-farm metering device	0.16	0.37
Water quantity problem	0.44	0.50
Water quality problem	0.04	0.02

METHODOLOGY

Mathematic programming model

Economic models for simulating agent behaviour are a widely used as tool for policy simulations. Actually, mathematic programming (MP) is a tool to support activities decision-making where limited activities and resources need to be managed and coordinated in order to optimize (maximize or minimize) an objective function. It allows to identify the best choices to achieve a certain objective respecting constraint that are imposed from the outside. It is widely used in the ex-ante analysis of water policies, through the simulation of the farmer's behaviour, in the hypothesis that the exogenous variables (allocation mechanisms) change. Therefore, this class of model allow the assessment of economic impacts and the adaptations that might be implemented by farmers in reaction to policies and or changes in water availability due to climate change. According to the literature, these tools have a long tradition for the analysis of irrigation issues (Hazel and Norton 1986, Howitt 2005). More recent applications of these models have concerned the simulation of the effects of water pricing or water markets in conditions of water scarcity (Garrido 2000, Perez-Blanco et al., 2020, Sapino et al., 2020) and on-farm technology adoption (Bartolini et al., 2012).

MP have been used at various scales ranging from the farm level (Gomez-Limon 2000 et al., Heumesser et al., 2012, Bhaduri et al. 2014) to the level of a large water system or country (Muhammad et al., 2014 and Zagonari et al., 2016).

In the current thesis project, a positive mathematical programming (PMP) model was applied. The peculiarity of this sub-class of model lies in the calibration stage. Indeed, it consists in introducing a non-linear cost function and sometimes even unobservable costs to replicate the baseline situation. The PMP is placed in the middle between programmings' deductive approaches and econometrics (inductive approach). Graveline (2016) reported a clear definition of such models according to Howitt (1995) "*The PMP approach is developed for the majority of modelers who, for lack of an empirical justification, data availability, or cost, find that the empirical constraint set does not reproduce the base-year results.*" However, PMP is not exempt from limitation. Although the introduction of non-linear function cost ensures a perfect calibration the model becomes often under-determined translating into a no unique solution.

In the present case the methodology allows the territorial scale simulation of different water pricing schemes, evaluating their effects in terms of consortium revenue, farmers' income, and water demand in a context of conjunctive use of water resources (surface and groundwater). The underlying assumption is that the implementation of water pricing scheme induces economic agents to a reaction expressed in terms of their decision variables.

The overall phases of the methodology are shown below:

- Direct interviews for primary farm data collection (crop pattern, water resource availability, water service type, socio-demographic features, main constraints faced by farmers).
- Identification of homogeneous farms group through *cluster analysis*
- Secondary data collection for model implementation
- Model building and validation
- Scenario definition
- Simulation and analysis of results

TERRITORIAL MODELING

Cluster Analysis

In order to adequately calibrate the model, a cluster analysis was carried out. This technique is an empirical method of classification and is considered an inductive method. It allows the detection of distinct and internally homogeneous groups of observational units. By identifying clusters within the sample, the aggregation effect bias is minimized allowing a representation as close as possible to reality. At the same time, the number of individuals models needed for simulations is strongly limited. In this way it will be possible to hypothesize the same objective function for each cluster and the related constraints. Therefore, a system of equations will be defined for each group of farms. The first step of the method consists of forming a matrix which represents the pairwise similarities of all objects being clustered. Subsequently, according to a specific algorithm, the method gradually builds clusters by merging the most similar objects together at each step. The final output can be represented by hierarchical trees or dendrograms (Blashfield et al., 1978). In order to group farm observations, Ward's method was applied here (Gomez-Limon et al., 2004). By means of this method, groups of homogenous data are identified, minimizing variance within clusters and maximizing variance between clusters. To measure the distance between elements, the Euclidean distance was used. The variables used as determinants for group observations are listed in Table xx. After the variables' standardization, the Kruskal-Wallis test was applied to test the general significance of each variable and the Dunn's Bonferroni as a pairwise test. It has been hypothesized that the differences between observations depended on farms' structural characteristics (land size, irrigated crop share, labour and water availability) and farmer characteristics (age, credit access and off-farm job). As reported in the paragraph on the sample description, this information was collected through face-to-face questionnaires. Therefore, we considered all variables listed in Table 5 to calibrate the cluster. A clear component of innovation compared to the pre-existing literature is the variable that considers the type of water service (self-supplied or collective service) adopted by farmers. Clustering was performed using SPSS Statistics 26 software.

Table 5 Variable used as determinants in cluster analysis.

Variable	Type	Code	Sample	
Farm characteristics			Mean	SD
Total land owned	metric	ha	43.92	57.87
Managed irrigated land	metric	ha	61.16	75.27
Irrigated land rent-in	binary	no =0; yes=1	29.25	44.70
Family workers	binary	no =0; yes=1	0.65	0.48
Extra-family workers	binary	no =0; yes=1	0.14	0.35
Irrigated crop pattern				
Tomato	metric	crop pattern (%)	11.79	25.84
Vineyards	"	"	25.01	37.39
Vegetables	"	"	16.49	32.28
Permanent vegetables	"	"	6.89	16.73
Olive grove	"	"	8.51	22.11
Intensive olive grove	"	"	9.70	25.26
Orchards	"	"	5	14.75
Cereals	"	"	4.70	14.44
Others	"	"	9.70	24.04
Water				
Water service	categorical	1= collective (%)	27.54	
		2= self-supplied (%)	53.62	
		3= both services (%)	18.84	
Multiple water services	binary	0=single; 1 multiple	0.18	0.38
On-farm metering device	binary	no =0; yes=1	0.15	0.35
Innovation in irrigation field[1]	binary	no =0; yes=1	0.14	0.34
Farmer characteristics				
Age	metric	years	50.18	11
Credit access	binary	no =0; yes=1	0.46	0.50
Off-farm job	binary	no =0; yes=1	0.21	0.41

The cluster analysis results are reported in Table 6. The output consists of four groups differing in terms of farm structural characteristics (land and labour endowment, irrigated crop pattern, water-related information) and farmer characteristics. This chapter provides analysis of results already published in Mirra et al., 2021.

Table 6 Cluster features.

	Cluster 1		Cluster 2		Cluster 3		Cluster 4		Sample	
N	16		37		12		4		69	
	Mean	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*	*Mean*	*SD*
Farm characteristics										
Total land owned	47.42	59.20	28.53	24.14	39.21	35.37	185	135.27	43.93	57.87
Managed Irrigated land	13.69	15.59	20.23	18.11	38.55	31.77	154.5	115.18	29.25	44.70
Irrigated land rent-in	0.12	0.35	0.16	0.37	0.75	0.45	0.75	0.5	0.28	0.45
Extra-farm workers	0	0	0.16	0.37	0.25	0.45	0.25	0.5	0.14	0.35
Irrigated crop share										
Tomato	4.23	11.57	1.12	4.20	50.81	37.13	23.63	25.13	11.62	25.19
Vineyards	4.37	13.15	44.68	41.33	0.23	0.80	0	0	24.65	37.24
Vegetables crops	0	0	22.72	38.45	11.61	18.57	39.49	43.36	16.26	32.10
Permanent Veg. crops	1.86	7.43	4.35	9.74	21.31	32.20	7.32	8.93	6.79	17.73
Olive grove	26.14	39.12	3.82	10.05	1.53	2.92	2.27	4.45	8.39	21.97
Intensive olive grove	25.95	42.31	5.72	16.00	0	0	10.71	21.42	9.56	25.10
Orchards	0	0	9.31	19.22	0	0	0	0	4.92	14.65
Cereals	8.26	22.58	2.71	9.92	7.68	14.88	0	0	4.70	14.44
Other	29.17	39.56	1.14	5.43	7.09	17.59	18.83	26.94	9.56	23.89
Water resource										
Water service type	1.5	0.51	1.89	0.51	2.33	0.88	2.5	1	1.91	0.67
Multiple water service	0	0	0.08	0.27	0.58	0.51	0.75	0.5	0.18	0.39
Water accounting	0.06	0.25	0.13	0.34	0.25	0.45	0.55	0.58	0.16	0.37
Farmer characteristics										
Age	55.69	10.76	51.93	9.43	41.83	8.18	41.75	12.5	50.3	10.91
Credit	0.19	0.40	0.43	0.50	0.83	0.38	0.75	0.5	0.45	0.50
Innovation	0	0	0.16	0.37	0	0	1	0	0.14	0.35
Off-farm	0.31	0.48	0.27	0.45	0	0	0	0	0.21	0.41

The first cluster identifies medium-large farms with an average of 13.69 ha of irrigated land, the lowest size among the groups. Hired labour is totally absent and the average farmers' age result to be the highest. The irrigated crop pattern is characterized by olive groves. All the observations included in this group rely on single water service.

The second cluster is the most representative of the study area, including 37 farms. The farms' size is considered small with an average of 28 hectares owned. The crops most represented are vineyards with 44.68 % of farm hectares. Only 3 observations out of 37 indicate a multiple irrigation service. During the last 5 years only 16% adopted irrigation-wise innovation.

The third farm type cluster includes 12 observations and larger farm size (on average 39.21 hectares owned). Furthermore, managed irrigated land increases up to 38.55 hectares. A major flexibility in augmenting farmland size is observed with 75% of farms with rent-in land. Labour hiring is raised until 25%. The irrigated crop pattern differs significantly from the previous groups: tree crops are almost absent in favour of tomato processing (58.81%) and permanent vegetables such as artichokes and asparagus (21.31%).

Multiple water services grow sharply with 58% of farms having such option. The average farmer age decreases while the percentage of those with access to credit increases. Those having an off-farm job are totally absent.

Finally, the fourth cluster identified is characterized by the largest farm size. As a consequence, the irrigated hectares of the entire sample are concentrated in this group. The mean values of the total land owned and the managed irrigated land amount to 185 and 154.5 ha, respectively. The values of managed irrigated land and extra-family workers are the same as for the cluster 3. The main irrigated crops are vegetables (fresh-cut crops, 46%) and tomato processing (25.13%). This group shows the highest values for the percentages of farmers who use the multiple water service (75%) and measure the water resource (55%). Moreover, farmer average age is 41 and all farms adopt innovations in the irrigation field. Finally, no farmer has an off-farm job.

It is possible to identify two macro-categories based on the entrepreneurial figure (Mirra et al., 2020). The first macro-category, consisting of clusters 1 and 2, includes farmers whose utility function is associable with the maximization of net income. The size, the irrigated crop pattern and the labour availability do not require high managerial skills nor a sufficient profitability as an exclusive activity. There is high level of own endowment for labour and capital. Whereas the second macro-category, consisting of cluster 3 and 4, includes farmers whose utility function could be associated with profit maximization. The size, the crop-pattern, the acquisition of land for rent, the access to credit and the age and off-farm job work are indicators of dynamism and flexibility, typical characteristics of a professional business management system (McElwee et al., 2005).

Crop pattern, especially irrigated corps, are the main difference that cluster analysis reports. Net income maximizer exhibits smaller farmland size and is basically specialized in permanent crops (i.e. orchards, vineyards and olive groves). By contrast, profit maximizer relies on larger farmland size and is oriented in arable crops (i.e. vegetables and processing tomato). A further important differentiation between the two macro-categories is the type of water service adopted. In particular, the net income maximisers indicate almost exclusively a single water service (collective or self-supplied), conversely, profit maximisers rely on multiple irrigation services.

Constraint analysis by clusters

The analysis of descriptive statistics allowed a clear clusters profiling in terms of entrepreneurial figure, irrigated crop pattern and water service type. As reported in the previous paragraph, the analysis ensured the identification of the utility objective function for each group. However, for model implementation this is not enough. Actually, in order to define the system equation for each cluster, the constraints formulation is required. This section provides the analysis of variables related to the constraints of farm activity (land, labour and capital endowment, water availability, CAP requirements). Each variable shown in the table 7 represents a Likert scale item. Therefore, for each of them the interviewee expressed a value from 1 to 5 based on the degree of impact that each constraint has in limiting the growth of their farm's activity.

Table 7 constraints variables.

Statistics	**Cluster 1**		**Cluster 2**		**Cluster 3**		**Cluster 4**		**Sample**		**Kruskal-Wallis test** (p-value)
Specialization	Olive Groves		Orchards and Vineyards		Processing tomato and permanent vegetables		Fresh-cut vegetables				
Observations	16		37		12		4		69		
Constraints to farm activity expansion	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	

Land availability	2.56^{a}	1.54	2.48^{a}	1.52	2.91^{a}	1.62	2^{a}	0.81	2.55	1.50	0.79
Rent/purchase land price	3.12^{a}	1.40	2.48^{b}	1.40	3.41^{a}	1.50	3.75^{a}	1.5	2.86	1.46	0.10*
Family wokers	3.75^{a}	1.73	3.64^{a}	1.13	3^{b}	1.41	1.5^{c}	1	3.43	1.41	0.02**
Extra-family workers	3.37^{a}	1.70	3.21^{a}	1.58	3.75^{a}	0.86	4.5^{a}	0.57	3.42	1.48	0.47
Water resource availability	2.37^{a}	1.20	3.16^{b}	1.57	2.66^{ab}	1.66	3.75^{b}	0.95	2.92	1.50	0.2
Collective water service adequacy	2.31^{a}	1.25	2.10^{a}	1.44	2.50^{a}	1.44	3^{a}	1.41	2.27	1.39	0.4
Credit access	1.75^{a}	1.18	2.29^{b}	1.45	2.50^{b}	1.08	2.75^{ab}	2	2.23	1.37	0.30
Compliance with CAP conditionality	1.65^{a}	1.12	2^{ac}	1.49	3^{b}	0.85	2.5^{bc}	1.29	2.11	1.37	0.006**

Note: different letter corresponds to significativity at $p < 0.1$, post-hoc Dunn's Bonferroni test

Kruskal-Wallis $*p < 0.1$, $**p < 0.05$

After the variables' standardization, the Kruskal-Wallis test was applied to test the general significance of each variable and the Dunn's Bonferroni as a pairwise test.

The results shows that labour, both family and salary, always represents a stringent constraint to farm's activity expansion. Regardless of the entrepreneurial figure, labour represents a very limiting factor. The average values relating to the work variables are always higher than 3 points, reaching a peak of 4.5 in cluster 4. Furthermore, clusters 3 and 4 report the high prices, both for sale and for rent, of agricultural land. It should be remembered that the most flexible and dynamic farms belong to these clusters for which the expansion of the surface, even if temporary, is a key factor. Compared to the water resource, cluster 4 seems to be the most affected by its availability, reaching 3.75 average points. These farms are the largest and most intensive.

Cluster Characterization

Based on the data analyzed so far, in this section we report a label for each cluster and a brief description.

- Cluster 1 (k1): *Extensive traditional farmers*

This cluster represents medium-large farms with 28% of irrigated land. It is mainly oriented towards extensive crops (traditional olive grove and cereals). The single water service is the most adopted (collective or self-supplied).
Objective function: net-revenue maximization
stated constraints: family and extra-family workers

- Cluster 2 (k2): *Fruit-producers traditional famers*
  This cluster represents the biggest proportion of sample, including 37 farmers. Mostly specialized in vineyards with 44.68% of farm hectares. the single water service is prominent.
  Objective function: net revenue maximization
  stated constraints: family and extra-family workers

- Cluster 3 (k3): *Professional fresh-cut vegetables farmers*
  This cluster include farmers with a more intensive production system. Managed irrigated land and the percentage of rent-in land increase. These farms are characterized by having a diversified plan of fresh-cut vegetables. Multiple irrigation water service is widespread (58%).
  Objective function: profit maximization
  stated constraints: family and extra-family workers, land prices.

- Cluster 4 (k4): *Large professional tomato processing farmers*
  The largest professional farms belong to this cluster. This is the smallest group in terms of observations. However, it includes the most portion of irrigated land (185 ha). Farmers are specialized in tomato processing cultivation. The multiple water service is always adopted.
  Objective function: profit maximization
  stated constraints: family and extra-family workers, land prices, water availability.

At this stage, a further criterion for the sample segmentation was used. In fact, within each cluster, farms were discriminated in three different farm types according to the water service adopted (f1 = collective, f2 = self-supplied, f3 = both). This step represents a strong element of innovation compared to the pre-existing literature. Actually, the water service type is rarely considered or is assumed to be available to all users without distinction (Dono et al, 2010, Portoghese et al., 2021). This step allows to reconstruct a water demand function for each cluster and each type of water service. Clearly, farmer's behaviour will be described in a greater degree of detail. Finally, the behaviour of 10 different farms unit is simulated.

Table 8 Farms unit by cluster and irrigation service type.

Farm units	Cluster (k)	Irrigation service (f)
1. k1f1	Extensive traditional farmers (8)	Collective
2. k1f2	Extensive traditional farmers (8)	Self-supplied
3. k2f1	Fruit-producers traditional famers (7)	Collective
4. k2f2	Fruit-producers traditional famers (27)	Self-supplied
5. k2f3	Fruit-producers traditional famers (3)	Both services
6. k3f1	Professional fresh-cut vegetables farmers (3)	Collective
7. k3f2	Professional fresh-cut vegetables farmers (2)	Self-supplied
8. k3f3	Professional fresh-cut vegetables farmers (7)	Both services
9. k4f1	Large professional tomato processing farmers (1)	Collective
10. k4f3	Large professional tomato processing farmers (3)	Both services

Note: Number of farms for each unit is reported in brackets.

Technical matrix

After the identification of homogeneous farms cluster, more detailed information relating to the farm management and organization were collected. The objective is to obtain technical parameters for the model definition. In order to obtain this information, the farm accountancy data network (FADN) was used. Specifically, prices and quantity of harvested products, production factors endowment, variable cost, the amount of CAP subsidies and water volumes were investigated. If some data was not available in FADN database, privileged witnesses were interviewed (consortium technicians, agronomists operating in the area, technicians from professional associations). The query for data extraction was built while taking the type of farming (TF or OTE) of each cluster into account. The extraction concerned only the farms falling within the province of Foggia and, accordingly to the privacy regulation EU 2016/679, a minimum of 5 observations were considered. The data relating to the crops of each cluster were collected by differentiating between irrigated and rainfed crops and by production techniques (conventional or organic). The average values reported in tables for each parameter refer to the time series 2016-2018. As expected, it is showed a higher profitability of irrigated crops compared to rainfed ones. More specifically, data confirms that the most intensive and profitable crops are represented by table grape (11667 €/ha-Gross margin) and tomato (6002 €/ha-Gross margin), respectively. In addition, higher profitability is observed for conventional crops compared to organic ones. Variable costs (Vcost) are the result of the average of different variables cost items (pesticides, fuel, rental, insurance, marketing). The parameter distribution is rather fluctuating; however, it is observed the more intensive the crops the higher its value (for i.e. fruit and tomato). Finally, the direct subsidies are reported only for organic farms and crops benefit from coupled payments (wheat, legumes, olive and so on). Indeed, according to the CAP, the aid for this class of crops is established on hectare base. Table 9 and 10 reports the overall technical parameters for each crop.

Table 9 - Technical parameters matrix for rainfed crops.

Rainfed Crops	Yield (q)	Price (€/q)	Vcost (€/ha)	Subsidy (€/ha)	Gm** €/ha
Wheat	40	29	280	100	980
Wheat*	34	34	258	148	1046
Field bean	25	20	120	25	405
Field bean*	19	26	138	148	504
Traditional olive grove	21	29	210	90	489

*Note: *asterisk indicates organic crops, ** excluding water, and labour costs.*

Table 10 - Technical parameters matrix for irrigated crops.

Irrigated Crops	Yield (q)	Price (€/q)	Vcost (€/ha)	Subsidy (€/ha)	Gm** €/ha
Wheat	50	24	320	100	980

Traditional olive grove	32	72	1200	90	1194
Intensive olive grove	47	55	558	90	2117
Wine grape	319	25	957	-	7018
Wine grape*	349	29	1479	856	9382
Table grape	359	39	2334	-	11667
Peach orchard	230	48	2155	-	8885
Asparagus	47	174	777	-	7401
Tomato	939	10	3388	-	6002
Cabbage	120	26	1208	-	1912
Fennel	200	18	1340	-	2260
Beet	500	3.30	1243	-	417

*Note: *asterisk indicates organic crops, ** excluding water, and labour costs.*

As regards the labour factor, in this model the general hypothesis is that the availability of work coincides with the labour requirement needed for its irrigated crop pattern. However, where farmers stated that labour does not represent a stringent constraint (Likert's median value equal or less than 3), this availability has been increased by 10-20%.

In order to formulate the labour constraints, data about labour requirements for each crop was extracted from FADN dataset. For both family and extra-family labour, data are expressed on a monthly basis, as reported by Giannoccaro et al. (2010). Instead, for the definition of the maximum labour limit we combined the data collected through the direct survey (number of workers available for each unit) with the information required by national employment contracts. Specifically, a full-time agricultural work contract provides for an employment of 1800 hours per year (equal to 225 days of 8-hour work). Conversely, for part-time work, 900 hours of work per year are considered. This procedure was carried out both in relation to family and extra-family workers.

As regards the water resource, the data on the water volumes use availability were collected through the questionnaire. In the same way as the labour constraint, the availability of resource matches with the water requirements except where the resource was not found to be a stringent constraint (where water availability was increased by 10-20%). However, this data does not refer to individual crops but to whole water used at the farm gate. Therefore, by combining this data with the academic literature (Smith et al., 1998, Rey et al., 2016) and technical documents reported on the web page of CBC, the water requirements for each crop were computed. On this basis, we assumed that the maximum limit of water available for each farm unit corresponded at least to the irrigation water requirement. Therefore, this was the assumption behind the water constraint definition. This constraint has been defined both for farmers adopting the collective service and the self-supply. From a methodological point of view, this aspect represents an important element of novelty. Indeed, in most simulation models involving both water services, groundwater is considered unlimited. According to Pulido-Velazquez et al., 2008: "most of the existing analytical solutions are developed for ideal homogenous and isotropic aquifers of infinite or semi-infinite extent". However, this deviates greatly from reality by providing distorted data about the elasticity of demand at the price of water for the two services.

Model building

The modeling approach adopted in this study is based on Positive Mathematical Programming (PMP) (Heckelei et al., 2012). The approach implemented was formally introduced by Howitt in 1995.

The model aims at simulating farmer's decision making of different farms type located in the area of the CBC. Since the study was conducted at a basin level, the territorial scale is adopted.

Other examples of studies carried out at the basin level using programming models applied in the same area were reported by Nardone et al. (2007), Bazzani et al., (2004) and Giannoccaro et al. (2010).

Regarding the objective function, the direct survey showed the presence of both concrete and pure entrepreneurs interested in maximizing net income and profit, respectively.

However, for operative reasons, the expected total gross margin $GM_{k,f}$ (i.e., total income minus variable costs) is considered as a proxy of farming profits in the short-run. The latter is defined as a mathematical function of farmers' decision variables, that is, the surface covered by the different crops. As observed in the equation of the objective function, the total gross margin is calculated for each cluster (indicated with k) and each irrigation water service (indicated with *f*). The definition of this set translates into a greater degree of detail allowing the assessment of the water policies effects considering the interplay of two different source of water (only for farms using both services).

The type of activities ($X_{c,k,f}$) included in the model represent the most important crops for the economy of the Capitanata such as wheat, olive oil, wine grapes, tomatoes, asparagus, peaches etc. The aforementioned crops were considered, depending on the cluster considered, in both rainfed and irrigated conditions. Moreover, the distinction between conventional and organic crops has been reported. This choice is justified by the percentage farms of the sample (40%) adopting organic production system and in general by the regional scenario. Indeed, the latest Sinab report identifies the Apulia region as the second region of Italy for organic agricultural surfaces (20%).

Maximization is subject to two types of constraints. The first refers to the production factors as identified by economic theory (land and labour).

To be accurated, although the technical matrix of labour was built, as explained in the previous paragraph, the labour constraint was excluded from the model. Indeed, according to Piro et al., (2015) often in southern Italy the high intensity of agricultural labour required lead to conditions of quasi-informal labour market. The latter, easily translate into a phenomenon of "social dumping" that hamper the identification of a labour matrix that correspond to the reality. For this reason, only the land constraint was considered in the modelization phase.

Specifically, the maximum availability of land (Eq.3) and the maximum availability of land for woody crops (Eq.10) was considered.

In fact, it is assumed that in the short term the amount of land destined for perennials crops cannot increase. Therefore $B_{k,f}$ represents the vector of perennial crops land for each cluster and farm type.

The second type of constraint refers to the availability of water resources. The water resource constraint was constructed taking into account the block water tariff imposed by the CBC. More specifically, the maximum limit of water resource for each consumption block was defined. The latter was calculated by multiplying, for each cluster, water requirements by the irrigated area of each crop and distributing it between blocks (considering the maximum limit of each block: 2050 m3/ha, 2051-3000 m3/ha, further amounts). This limit has been reported in model equation as $wcbc\_rhs_{wblock,k,f}$.

In a specular manner, the constraint related to the water cost was built. Indeed, the quantity of water used for each block has been multiplied by the corresponding tariff (0.12-0.18-0.24 m^3 / ha). Furthermore, as regards to groundwater constraint, the limit has not been divided into blocks. The latter corresponds to the volume withdrawn from the well as declared by farmers and it is indicated as $rhs\_self_{k,f}$.Finally, the costs were calculated by multiplying this quantity by the cost estimated in Mirra et al., 2021 (0.23 € / m^3).

The model assumes the following structure:

$$Max\ Z\ (\boldsymbol{X_{c,k,f}}) = \sum_{k,f} GM_{k,f} \qquad \forall\ k,f \qquad (1)$$

$$GM_{k,f} = \sum_{c,k,f} (price_{c,k,f} * yield_{c,k,f} - vcost_{c,k,f} + subsidy_{c,k,f} - Kw_{k,f} * wat\_req_{c,k,f})\boldsymbol{X_{c,k,f}} \qquad \forall\ k,f \qquad (2)$$

$$\sum\nolimits_{k,f} \boldsymbol{X_{c,k,f}} \leq size_{k,f} \qquad \forall\ k,f \qquad (3)$$

$$\sum\nolimits_{c} X_{c,k,f} * wat\_req_{c,k,f} \leq \sum\nolimits_{wblock} \boldsymbol{aqwat\_cbc_{wblock,k,f}} + \boldsymbol{aqwat\_self_{k,f}} \qquad \forall\ k,f \qquad (4)$$

$$\boldsymbol{aqwat\_cbc_{wblock,k,f}} \leq wcbc\_rhs_{wblock,k,f} \qquad \forall\ wblock,k,f \qquad (5)$$

$$\boldsymbol{aqwat\_self_{k,f}} \leq rhs\_self_{k,f} \qquad \forall\ k,f \qquad (6)$$

$$kwat\_cbc_{k,f} = \sum\nolimits_{wblock} \boldsymbol{aqwat\_cbc_{wblock,k,f}} * pwat_{wblock} \qquad \forall\ k,f \qquad (7)$$

$$kwat\_self_{k,f} = \boldsymbol{aqwat\_self_{k,f}} * pwat\_self_{k,f} \qquad \forall\ k,f \qquad (8)$$

$$Kw_{k,f} = (kwat\_cbc_{k,f} + kwat\_self_{k,f})/(\sum\nolimits_{wblock} wcbc\_rhs_{wblock,k,f} + rhs\_self_{k,f}) \qquad \forall\ k,f \qquad (9)$$

$$X_{k,f} \leq B_{k,f} \qquad \forall\ k,f \qquad (10)$$

$$X_{c,k,f} > 0 \qquad \forall\ k,f \qquad (11)$$

where: GM_{kf} is the Gross Margin of crop c for each cluster ad farm type.

$price_{k,f,c}$ is the price of crop c for each cluster k and farm type f.

$yield_{k,f,c}$ is the yields of crop c for each cluster k and farm type f.

$x_{k,f,c}$ land area (ha) of crop c for each cluster k and each farm type f.

$Vcost_c$ variable cost of crop c for each cluster k and each farm type f.

$size_{k,f}$ total amount of area available for each cluster k and each farm type f.

$water\_req_{ck,f}$ water requirement for each crop c and each cluster and farm type f.

$aqwat\_cbc_{wblock,k,f}$ amount of cbc water for each block each k and each farm type f.

$aqwat\_self_{k,f}$ groundwater used for each cluster k and each farm type f.

$wself\_rhs_{k,f}$ limit of groundwater available for each cluster k and farm type f.

$wcbc\_rhs_{wblock,k,f}$ limit of cbc water available for each cluster k and farm type f.

$kwat\_cbc_{k,f}$ water cbc cost for each k and each farm type f.

$kwat\_self_{k,f}$ water self cost for each k and each farm type f.

$pwat_{wblock}$ water price for each tariff block (0.12-0.18-0.24 €/m^3).

pwat_self water price for groundwater (0.23 €/m^3).

Kw unit cost for water taking into account cbc cost and groundwater cost.

The model variables are shown in bold; the rest are the parameters.

This represents the general model implemented in order to represent the reference year (Baseline). However, during the phase of drought scenario implementation the water resource constraint are modified in order to simulate the two different water pricing policy (current drought and alternative priority water tariff scheme). For further information see the chapter “simulated scenario”.

Model Calibration

A crucial phase for the implementation of a mathematical programming model is the calibration. Indeed, a model properly calibrated should match conditions of farm production and resource use in a base year. According to Howitt (1995) policy evaluation based on programming models lack credibility when they show a divergence between base period model outcomes and actual results. As previous clarified in this work, the Positive Mathematical Programming, following Howitt approach (1995) is implemented.

In particular the Howitt approach has been integrated with the average cost approach proposed by Heckelei and Britz (2000).
The PMP is characterized by automatic calibration which reduces the time-consuming problem typical of classic LP models. Indeed, researchers has to characterize actual managerial or resource constraint the observed situation (Graveline et al., 2016).
The reason for choosing Howitt method is twofold. First, since it allows the addition of exogenous information (i.e new alternative rainfed crops), the method shows a high degree of flexibility, facilitating its application to a wide range of case studies and resulting more realistic. Second, this approach allows to capture much of the farm’s behavioural response in heterogeneous contexts (Heckelei and Britz, 2005) such as the area of Capitanata.
The method considers that the average costs estimated by the variable costs function of each crop activity are equal to the observed costs. In this way, through the PMP application the crops’ gross margin turn out to be equal to gross margin observed.
The implementation of this standard approach to PMP consists of two phases.
The first of these is the construction of a profit maximisation model to which are added a series of additional restrictions (calibration constraints), which limit the area allocated to each crop to the areas observed in reality.
Including such constraints, the optimal solution of the model is forced to reproduce exactly the levels of activity (irrigated crop area) observed in the base year.
In the second phase, the dual values (shadow price) of the calibration constraints are used to specify a target profit maximization function with quadratic costs, as described below.
MaxMB = $\sum_{c,k,f}(price_{c,k,f} * yield_{c,k,f}) * x_{c,k,f} + S_c x - \alpha_{c,k,f} * x_{c,k,f} - \frac{1}{2}\beta_{i,j} * x^2{}_{c,k,f})$

1) $\alpha_{c,k,f} = CV_{c,k,f} - \lambda_{c,k,f}$
2) $\beta_{c,k,f} = \frac{2\lambda_{c,k,f}}{x^{obs}_{c,k,f}}$

where λ_i is the shadow price (dual value) of crop calibration restriction i and α_i and β_i are the parameters of the PMP calibration.
λ_i is obtained through the calibration constraints.
Hence, the objective function includes a quadratic cost function that considers all the costs of the different crops, both observable and non-observable.

The interest of this objective function is that its maximization allows to reproduce in an exact way the cultivation plan of the farms modelled for the base scenario used for calibration. Further information about the standard PMP and average cost approach can be found in Heckelei and Britz (2005).

Simulated scenario

Socio-economic scenarios are relevant tool for exploring the long-term consequences of anthropogenic climate change, and the options available to address them. They have been applied for different purposes and to different degrees in several areas of climate change analysis, typically in combination with projections of future climate change (Kriegler et al., 2010).

The process of setting-up a scenario leads to the identification of hypotheses about the future.

The focus is not on predicting the probability of a phenomenon occurrence but rather describing a potential situation that could alter the observed reality.

The basic assumption for defining a scenario is that the future cannot be predicted but exploring it allows the improvement of the current decision-making process.

A future scenario is built through the convergence of various driving forces that could arise in the future. The external forces identifying a scenario are called “vectors of change” (Giannoccaro, 2010).

However, to avoid complicating the process of definition and subsequently the results analysis, generally the focus is on one or a few ‘vectors of change’, the remaining are assumed invariable.

In this thesis project the scenario concerns the modification of an environmental factor.

More precisely, the scenario to simulate concerns the occurrence of a hydrological drought phenomenon translating into a reduction of the water resources availability that the CBC distribute to farmers.

The data and information obtained provide the parameters for the formulation of mathematical simulation models. The hydrological scenario is described in the following paragraph.

Drought scenario in CBC area

As pointed out, the study area analysed in this thesis is located in an area of Consortium of Reclamation of the Capitanata served by two collective irrigation water schemes, namely Fortore and Sinistra Ofanto. Both are equipped with modern, pressurized, on-demand delivery services. The Fortore water scheme withdrawn water from the Occhito and Capaccio dams. Conversely, the Ofanto scheme relies on Rendina and Capacciotti and the branch cross on the river Atella.

Average annual volumes delivered by collective services amounts to 103 Mm^3. However, since the CBC endowment depends on the winter rainfall trend, in the last decades periodic water shortage have undermined the reliability of the collective water service.

Indeed, Giannoccaro et al. (2019), by analysing the irrigation manifests of the CBC over a 12-year investigation period, identified three different hydrological conditions: i) full resource availability ii) intermediate availability iii) totally unavailability.

Furthermore Portoghese et al. 2020, investigate the effect of different water pricing schemes on the same study area. The authors, by analysing climate information and hydrological datasets over the period 1993-2012 identified different hydrological scenarios (regular, abundant and drought conditions) where the drought scenarios correspond to the half of the average annual volumes that CBC normally distribute.

Based on this evidence, the hydrological scenario simulated in this project is defined. The latter is characterized by a 50% reduction in the volumes distributed by the consortium in ordinary hydrological years. More specifically, the total volume of water used by the farmer's sample in ordinary years is 1,8 Mm^3 which translates into 930,241 m^3 when the hydrological scenario is implemented, and the reservoirs are almost empty.

Moreover, the total irrigation requirements of irrigated crops in the Capitanata are not fully met by collective water service. Indeed, number of farms integrate the collective water service with self-supplied one.

Farmers can directly withdraw resources from the surface water network including the River Basins of Candelaro, Cervaro and Carapelle, although this alternative source represents only a small part of the necessary irrigation volumes. In fact, a large part of the irrigation needs of the Capitanata, is satisfied by groundwater pumped from private-afforded well.

Within this work, the total amount of groundwater accounts for 1,9 Mm^3.
In this case, the drought scenario does not provide with a decrease in groundwater volumes.
According to Sahid et al., 2010 groundwater droughts are generally out of phase with both meterological and agricultural droughts.
Groundwater is the last component of the hydrological cycle affected by drought translating into a temporal lag behind the deficient precipitation. For this reason, since the simulation implemented in this thesis is a short-run simulation, the total amount of groundwater volumes is not reduced of 50% as well as the CBC water supply.

Water pricing policies simulation

Baseline

Status Quo: In ordinary hydrological conditions the water pricing scheme adopted by the CBC is characterized by a binomial payment: (i) a yearly fixed component related to the farm irrigated area (60 €/ha); (ii) a volumetric three-tier water tariff scheme based on irrigation water used (0.12 €/m^3 with a unit volume under 2050 m^3/ha; 0.18 €/m^3 with a unit volume ranging from 2051 to 3000 m^3/ha; 0.24 €/m^3 for further amounts). The block tariff aims at encouraging the saving of the resource and at the same time to guarantee a minimum water endowment accessible to all farmers. The blocks which are variable from year to year depending on the hydrological state of the reservoirs feeding the collective water scheme and is designed to discourage farmers' uptake from the CBC network when the first block threshold is exceeded.
While for groundwater use a limited volume of water is calculating combining data on actual crop water requirements and farmers self-evaluation of groundwater depletion. According to Mirra et al., 2021 the average cost for self-supplied groundwater service is 0.23 €/m^3.

Drought scenario

Status Quo: In drought conditions (when at the beginning of the irrigation season the volume available in dams is strongly reduced) the system of contribution in block-tariff is modified. During drought years, the scarcity pricing approach is much more restrictive as regards to unit water costs and block thresholds.

Generally, the CBC, according to the proportional rationing method, increases tariff unit cots blocks and decreases the water allotment equally for all the users. More precisely, in this study the total water distributed by CBC is reduced of 50%. The allotment of the first block decreases reaching 1050 m^3/ha which correspond a unit price of 0.18 €/m^3, for further amounts (if any) the unit price rises to 0.24 €/m^3. In general terms, allotments for each block are reduced (unavailability of supply) and the unit price for each block is increased.

The average cost of groundwater use remains unchanged as regards the baseline simulation (0.23 €/m^3).

Priority: Even in this case the simulation takes place in a condition of 50% reduction of the water resource distributed by the consortium (the hydrological scenario is the same). However, the CBC does not apply the proportional rationing method. In this simulation the water allotment of the CBC is differentiated based on security-differentiated priority rule.

More specifically the total water available in CBC dams is divided in two different water security classes: general water which corresponds to the 80% of the total volume distributed by CBC in drought conditions. This quantity is subject to block tariff scheme imposed in regular years (0.12 €/m^3 with a unit volume under 2050 m^3/ha; 0.18 €/m^3 with a unit volume ranging from 2051 to 3000 m^3/ha; 0.24 €/m^3 for further amounts). So, even if the quantity available is reduced the pricing scheme is not increased.

The remaining 20% of water represents the second water tariff class: priority water.

The latter, is a common and exchangeable water resource amount among all clusters. The innovativeness of the proposed reform lies in the fact that priority water is not allocated according to the current water right system (based on hectar-right owned by farmers): the consortium identifies the price as the economic tool for water allocation among users. The priority water is set at 0.20 €/m^3 (0.02 cent more than the second threshold of the block tariff) in order to verify the farm's propensity to pay more for more reliable water source.

The hypothesis of this pricing rule is that the model, through the instrument of water pricing, will allocate the priority water to farms having a more rigid water demand function. The latter are supposed to be more willing to pay a higher price to reduce the risk, maintain their irrigated crop pattern and in general mitigate the negative effects related to drought events.

In order to simulate the *priority_pricing* the model structure described in the paragraph "model building" show a modification. In particular, equation (4), (5) and (6) were replaced by the following constraint:

$$\sum_{c} watreq_{c,k,f} * X_{c,k,f} \leq \sum_{wblock} \boldsymbol{aqwat\_cbc\_gr}_{\boldsymbol{k,f,wblock}} + \boldsymbol{aqwat\_cbc\_pr}_{\boldsymbol{k,f}} + \boldsymbol{aqwat\_self}_{\boldsymbol{k,f}} \quad \forall \text{ k,f}$$

$$\sum_{wblock} \boldsymbol{aqwat\_cbc\_gr}_{\boldsymbol{k,f,wblock}} + \sum_{k,f} \boldsymbol{aqwat\_cbc\_pr}_{\boldsymbol{k,f}} \leq water\_cbc\_drought \quad \forall \text{ k,f}$$

$$\sum_{k,f} \boldsymbol{aqwat\_cbc\_pr}_{\boldsymbol{k,f}} = 0.20 water\_cbc\_drought \quad \forall \text{ k,f}$$

where:

$aqwat\_cbc\_gr_{k,f,wblock}$ is the general water from the CBC used during drought.

$aqwat\_cbc\_pr_{k,f}$ is the priority water from the CBC used during drought.

water_cbc_drought is the total amount of water available during drought.

Moreover, equation (7), (8) and (9) do not compare anymore because, as explained in paragraph "model calibration", costs result all included in α and β parameters.

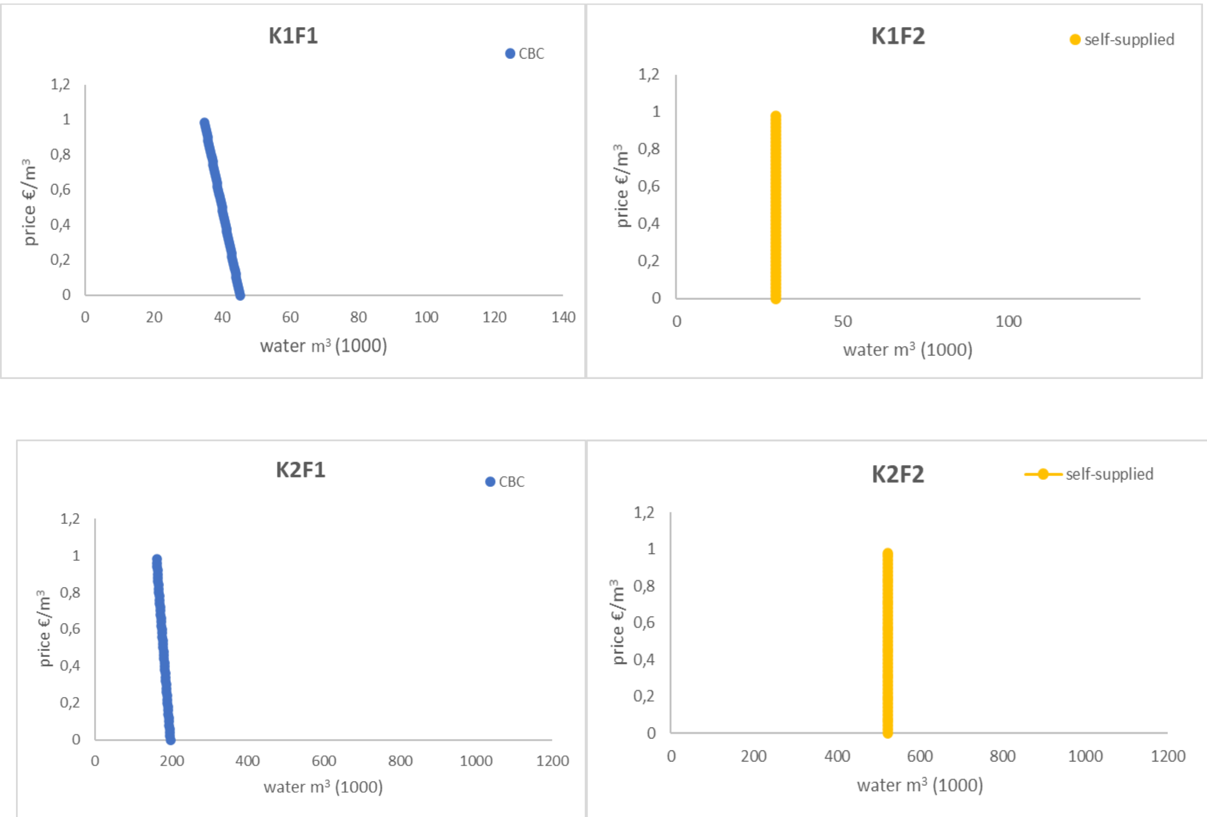
RESULTS

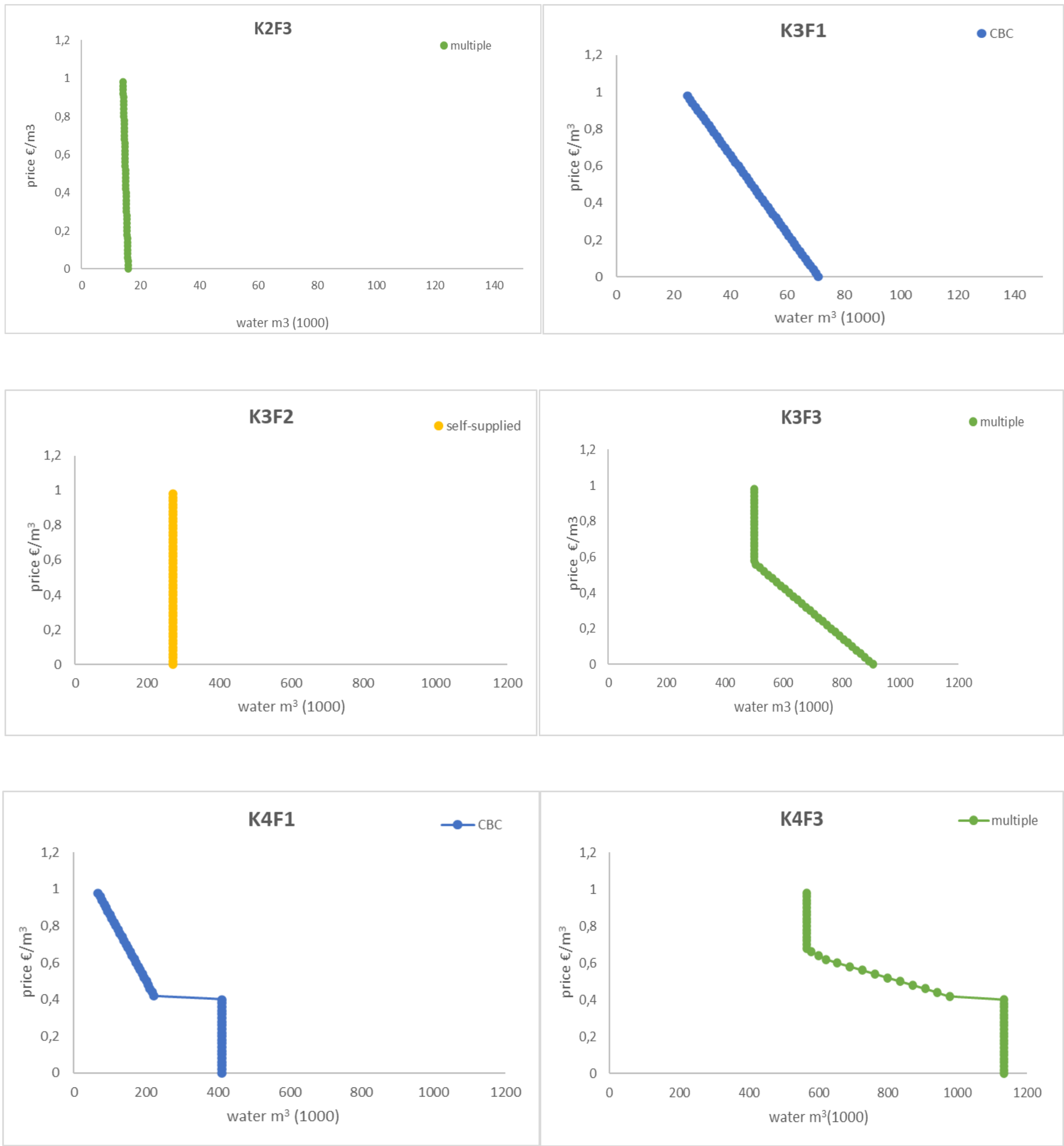
Baseline scenario

First of all, model results report figures of *Baseline* which condition refers to normally available water resource from CBC services charged by tree-block tariff scheme.

The first result of the PMP model implementation concerns the water demand curves of the farms belonging to the sample analysed. Therefore, the first simulation is based on the parameterization of the water pricing scheme according to the discrete pricing thresholds adopted by the CBC during regular hydrological conditions (here after Baseline).

Figure 7- Water demand functions for each cluster ('k') and each irrigation services type ('f').





Parameterization was carried out on the water pricing scheme imposed by the CBC. Therefore, as observed in the figure the demand functions of farms adopting only self-supply water service (yellow curves) are perfectly anelastic. Indeed, the unit price of the service is supposed to remain unchanged (0.23 €/m^3). The remaining farms use the CBC collective service either exclusively (blue curves) or integrating it with the self-supply service (green curves).

Overall, all demand curves show negative slope.

From a mathematical point of view, the inverse of demand’s slope (considering percentage and not absolute variations) represents its elasticity. Therefore, it is possible to analyse how farmers react to water pricing scheme increases by observing the different slope characterizing each function.

As well documented, a crucial factor in determining the demand elasticity for a good or service is the availability of substitute goods (i.e. water source). The higher the degree of factors substitutability the higher the demand elasticity.

In this case study, the water demand elasticity is affected by two key factors of substitutability: a technical factor (type of crops cultivated by farmers) and a structural factor (type of irrigation service adopted).

Scheme 1 summarised the determinants in water demand elasticity as regards the sample analysed.

Scheme 11 - Determinants of water demand elasticity.

Techincal factor: Crop pattern				**Structural factor:** Irrigation water service type		
Arable crops		Permanent		Collective (CBC)	Self-supplied	Multiple service
Rainfed alternative	Exclusively Irrigated	Rainfed alternative	Exclusively Irrigated	Absence of substitutability	Absence of substitutability	Substitutability

The table, on the left, divides the crops into two categories "arable" and "permanent". In short period, farmers can reduce irrigated land on arable crops while permanent ones are kept invariant, which makes orchard-specialized farms lesser elastic. Furthermore, within each category the crops can be exclusively irrigated or have a rainfed alternative. This aspect greatly affects the reactivity of the cluster to increases in the price of water, actually, farmers that cannot convert the production technique (from irrigated to rainfed) will have a more rigid demand.

On the other hand, the right side of the table concerns the water resource access.

This aspect is also relevant, clusters adopting both water services ('f3') have the opportunity to avoid the negative effects of price increase by switching to some extent with the self-supplying service, resulting in more demand elasticity.

This dynamic was also confirmed by the interpretation of the dual values relating to the constraint of the water resource.

Indeed, for farms adopting both irrigation water services, the constraint is less stringent, and the marginal increase of water resource translate into a small increase in overall gross margin.

In order to give an overview of the simulation results, two graphs reporting all the water demands function of CBC users are shown below.

Since the volumes magnitude used by farms is quite heterogeneous, the demand curves have been divided into two graphs allowing a better graphical analysis.

As can be observed, farms belonging to clusters 3 and 4 (large and professional with high value crops) have water demand curves shifted to the right side of the graph.

This translates into a more efficient water use, in fact, at the same price the level of water consumed is higher.

Vice versa for farms belonging to cluster 1 and 2 (small-size and extensive crops).

Figure 8 Water demand functions of farms adopting CBC water service (volumes less than 70.000 m3)

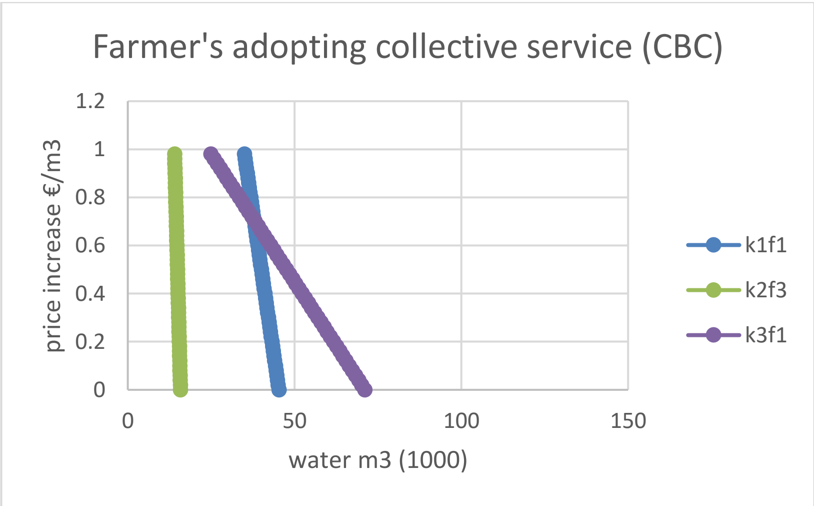
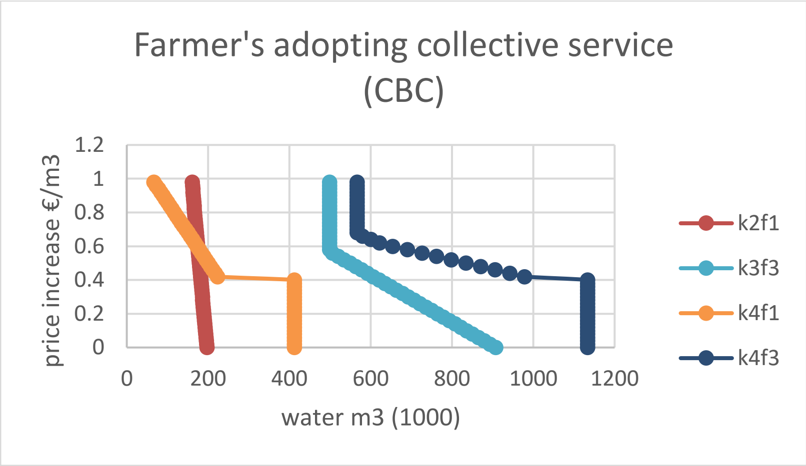


Figure 9 Water demand functions of farms adopting CBC water service (volumes less than 1,1 Mm3)



The analysis of the elasticity of each cluster is carried out by analyzing the curves shown in Figure 8 and 9 combined with data reported in Table 12.

The latter shows the elasticity determinants for each farms following the same setting of scheme 1.

Table 12 - Determinants of water price elasticity applied to the sample analysed.

	Techincal factor: Crop pattern				**Structural factor:** Irrigation water service type		
Farm category	Arable crops		Permanent		Collective (CBC)	Self-supplied	Multiple service
	Rainfed alternative	Exclusively Irrigated	Rainfed alternative	Exclusively Irrigated	Absence of substitutability	Absence of substitutability	Substitutability
K1F1	-	-	Olive	-	YES	-	-
K2F1	-	-	Olive	Grapewine, asparagus	YES	-	-
K3F1	-	Tomato	-		YES	-	-
K4F1	-	-	-	Tomato, chards, cabbage	YES	-	-
K2F3	-	-	-	Grapewine	-	-	YES
K3F3	Wheat	Tomato, cabbage, fennel	Olive	Asparagus	-	-	YES
K4F3	-	Tomato, fennel, cabbage	Olive	Asparagus	-	-	YES

As a result, the demand curves showing the greatest traits of inelasticity are for k1f1, k2f1, k2f1, k3f1,k4f1 farm categories.

Although these farms belong to three different cluster, they all adopt only the collective water service ('f1'). More specifically, the major inelasticity of their demand curves could be explained by the absence of substitutability of the irrigation water service.

This condition result to be exacerbated for farms k2f1, k3f1,k4f1 having a crop pattern in which the incidence of exclusively irrigated crops (tomato, asparagus,cabbage,chards) is rather high. Therefore, these farms show aspects of extreme rigidity: absence of substitutability and exclusively irrigated crops.

By contrast, farms k3f3 and k4f3 show flatter demand functions result to be more elastic to the water policy implemented. As shown in the table, these farms all adopt the multiple water service.

However, farms k4f3 have several crops "exclusively irrigated" resulting in traits of demand curve rather inelastic. When the water price increase, they cannot adapt their crop pattern in the short run, so the water quantity demanded barely change.

A greater elasticity is shown by k3f3 where besides the presence of "exclusively irrigated crops", it has rainfed wheat.

In conclusion, the simulation of the baseline scenario returned rather diversified and heterogeneous results. The combined analysis of the water demand functions, and the table of key factors have allowed to observe farm's reaction to CBC tariff's increases.

On balance, these first results show a demand price elasticity rather diversified among farmers. Moreover, the type of water resource access result to have a crucial role in determining farmers behaviour. The result confirms one of the theoretical preconditions for the design by the CBC of a differentiated pricing policy for groups of farmers. As pointed out in the previous chapters, in fact, in order for the CBC to successfully implement a water pricing must know users' willingness to pay or alternatively have this information for groups of users.

Tariff simulations' results

The results of the simulations carried out at territorial level through the Positive Mathematical Programming model (PMP), represent the second research results. These are reported in the following tables (13,14,15). For each farm category, gross margin, water use both from self-supplied and collective services, and CBC's revenue are reported.

Table 13 shows the results obtained from the model optimization in regular hydrological conditions and status quo water policy implementation (Baseline). While Table 14 and 15 refers to the drought scenario. Within the drought scenario simulation, results are separated for each water tariff's CBC simulated ('Status Quo' that correspond to the proportional rationing method normally implemented by the CBC during drought events and "Priority", the alternative water tariff mechanism based on security-differentiated rule).

As shown in the table, results are analysed in terms of variables of interest both for the farmer (Gross Margin), the Consortium (Revenue) and the environment (quantity of water both surface and groundwater).

Furthermore, for each variables analysed, the percentage difference (Δ%) compared with the Baseline scenario is reported.

Table 13 Baseline simulation results

Baseline	GM		Water (m^3)	Water_cbc (m^3)	Water_self (m^3)	CBC Revenue(€)
Status Quo	(€)	(€/ha)				
K1F1	341.33	926	45.36	45.36	0.00	10.89
K1F2	261.87	831	29.92	0.00	29.92	0.00
K2F1	694.06	5736	197.27	197.28	0.00	47.35
K2F2	2162.21	3528	523.35	0.00	523.35	0.00
K2F3	97.59	2602	15.83	6.33	9.50	0.76
K3F1	188.08	1272	71.12	71.12	0.00	17.07
K3F2	344.31	2690	272.03	0.00	272.03	0.00
K3F3	910.50	2320	908.13	408.66	499.47	46.12
K4F1	262.05	873	412.54	412.54	0.00	99.01
K4F3	1560.28	1894	1134.01	540.88	534.80	64.18

* values are reported in thousands except for GM €/ha.

As shown, the simulated farms show a rather varied profitability.

Since the farm dimension is very variable, in addition to the value of the total gross margin

for each farm, the value per hectare has been reported.
As a result farms with a greater economic profitability belong to cluster 2 which is the most representative cluster of the sample and is characterized by a crop specialization in orchards (mostly grapewine, peach and olive).
Then, the highest gross margin values are found in cluster 3 and cluster 4 specialized respectively in vegetable crops (cabbage, fennel, chard, asparagus) and processing tomatoes.
Finally, the lower values are found for cluster 1 which is characterized by extensive crop pattern, mostly rainfed and a small share of irrigated olive tree (7% of total area).
As regards the water resource, in general the greater volumes are concentrated in farms with more intensive crop pattern.
Therefore, each farm will contribute in a very different way in determining CBC revenue. Consequently, this will be null for farms “f2” including only water self-supply adopters. Figure 10 shows the contribution of each farm in determining the total CBC revenue.

Figure 10 Farm's contribution to CBC revenue

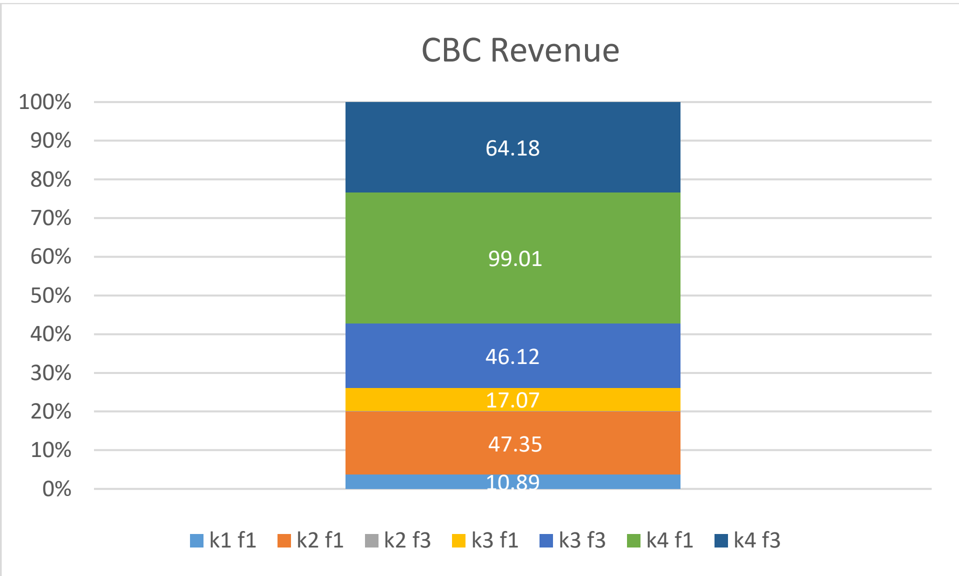


Table 14 Drought scenario results: "status quo" pricing policy.

Drought Scenario	GM	Δ%	Water	Δ%	Water_cbc	Δ%	Water_self	Δ%	Revenue	Δ%
Status Quo pricing										
K1F1	320.11	-6%	24.95	-45%	24.95	-45%	0.00	0%	4.49	-59%
K1F2	261.87	0%	29.92	0%	0.00	0%	29.92	0%	0.00	0%
K2F1	593.69	-14%	118.36	-40%	118.36	-40%	0.00	0%	23.71	-50%
K2F2	2162.2	0%	523.24	0%	0.00	0%	523.24	0%	0.00	0%
K2F3	96.60	-1%	14.24	-10%	4.75	-25%	9.50	0%	0.85	12%
K3F1	176.92	-6%	42.67	-40%	42.67	-40%	0.00	0%	9.49	-44%
K3F2	344.31	0%	272.03	0%	0.00	0%	272.03	0%	0.00	0%
K3F3	877.92	-4%	749.20	-18%	249.73	-35%	499.47	0%	45.70	-1%
K4F1	166.01	-37%	206.27	-50%	206.27	-50%	0.00	0%	37.13	-63%
K4F3	142.8	-9%	850.51	-25%	283.50	-48%	567.01	6%	51.03	-20%

In table 14 the percentage values indicate how far "status quo" water policy during drought differs from the baseline.

As regards the Gross Margin, as expected, in drought scenario the values show a decrease in all farm categories. When resource availability is reduced, farmers either replace high-income crops with the rainfed alternative or reduce crop surface. This behaviour, translate into an overall decrease in gross margin. Overall, the aggregate gross margin reduction compared to the baseline scenario corresponds to 6%.

The highest losses are found in farm k4f1 showing a decrease of 37 percentage points. Indeed, this farm has a very low level of factor substitutability: i) unavailability of alternative water source (absence of self-supplied water service) and very few rainfed alternatives (irrigated crop pattern mostly characterized by fresh-cut vegetables exclusively irrigated). As explained, the combination of these two factors justifies the impact on the different farms. For instance, farm k2f3 shows a variation in GM of only -1%. In fact, having the possibility to withdraw from groundwater it is not obliged to reduce its irrigated area.

With reference to the water distributed by the consortium called "water_cbc", the percentages of deviation from the baseline scenario are explained by the same reasons.

Actually, in this case the resource is reduced by 50% and the unit price for each tariff threshold has increased. As a result, it is observed that where farms show a lower degree of flexibility (see k4f1) the difference in water used with the baseline coincides exactly with 50%. By contrast, where farms can replace with rainfed crops or access the private-well, the difference is smaller.

The different distribution of volumes served by the CBC among farms is reflected in a different contribution in defining the consortium's revenue. The higher the consumption, the higher the value of Revenue derived from each farm.

On balance, the aggregate revenue reduction as regards the baseline scenario accounts for 4%.

Table 15 Drought scenario results: "priority" pricing

Drought scenario	GM	Δ%	Water	Δ%	Water_cbc	Δ%	Water_self	Δ%	Revenue	Δ%
Priority pricing										
K1F1	335.97	-2%	40.03	-12%	40.03	-12%	0.00	0%	12.43	14%
K1F2	261.87	0%	29.92	0%	0.00	0%	29.92	0%	0.00	0%
K2F1	672.50	-3%	179.41	-9%	179.41	-9%	0.00	0%	54.71	16%
K2F2	2162.21	0%	523.24	0%	0.00	0%	523.24	0%	0.00	0%
K2F3	97.21	-1%	14.92	-6%	5.43	-14%	9.50	0%	1.27	67%
K3F1	179.44	-5%	47.35	-33%	47.35	-33%	0.00	0%	12.00	-30%
K3F2	344.31	0%	272.03	0%	0.00	0%	272.03	0%	0.00	0%
K3F3	880.10	-3%	699.26	-23%	199.79	-48%	499.47	0%	23.97	-48%
K4F1	168.20	-36%	199.65	-52%	199.65	-52%	0.00	0%	37.12	-63%
K4F3	1420.07	-9%	825.60	-27%	258.60	-52%	567.01	6%	43.11	-33%

Table 15 has the same structure as Table 14 but refers to the "priority" pricing policy. In general, the percentage shows minor deviation with respect to the baseline scenario, highlighting a better resource reallocation. It results that when CBC applied priority water tariff scheme the gross margin losses are smaller than those faced with Status Quo tariff's scheme, translating into a lower negative impact of the economic production system. The general gross margin is reduced by only 4% compared to the baseline scenario, guaranteeing a 2% reduction in losses compared to the "current drought" scenario.

A further point of interest concerns the CBC revenue. The results show that in drought conditions the losses borne by the CBC are smaller when the priority water tariff scheme is applied. For some farm's type (k1f1, k2f1, k2f3) the revenue amount is also higher than the revenue obtained during ordinary years.

These results, verify the hypothesis of this model.

By applying a water pricing scheme based on a priority rule the total water available is efficiently reallocated resulting in minor economic losses both for farmers (in terms of

Gross Margin) and for Consortium (in terms of Revenue). More specifically, the total amount of CBC revenue corresponds to 285.000 € in the reference year (baseline), 172.000 € in drought scenario by applying proportional rationing method and 184.000 € in drought scenario by implementing the water tariff based on priority rule, leading to an increase in cost recovery of 7%.

As regards the variables relating to the water resource showed both in table 14 and 15, they are distinguished in “water” (total amount of water used) "water_cbc" (water derived from collective service) and "water_self" (water self-supplied by private well).

The total amount of water distributed by the consortium in ordinary years (status quo) corresponds to 1,7 Mm^3. While, in drought scenario is reduced of 50%.

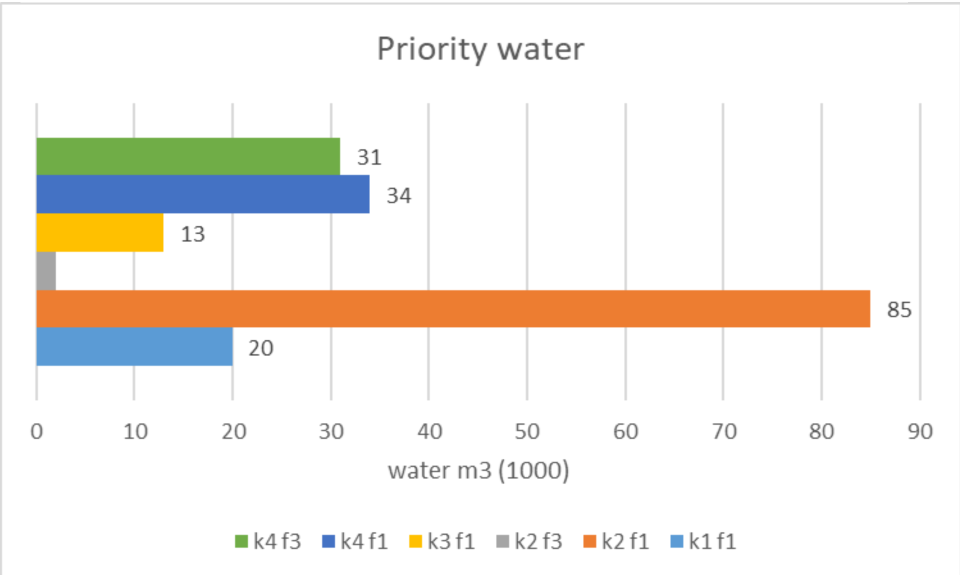
The total amount of water during drought is the same regardless of water tariff’s scheme (‘Status Quo’ or ‘Priority’). However, observing the results in table 14 and 15 the volumes distribution among farms is rather different, highlighting a significant water reallocation.

In particular, larger quantities are observed (and therefore smaller percentage differences compared to the baseline) in farms that in addition to general water have also purchased great amount of priority water, bearing a higher unit price (table 15).

Conversely, farms with more elastic demand curves and a lower willingness to pay for additional quantities of resources, show lower volumes (and greater percentage differences compared to the baseline).

In figure 11 is reported farms purchasing priority water.

Figure 11 Farms purchasing priority water



According to the previous results, farms buying priority water are those with more inelastic water demand function. More specifically farms adopting only water collective service ('f1', without substitute in water access) and farms with both irrigation water service with lack of rainfed alternative (k2f3,k4f3). However, although six clusters purchase priority water, only four of them manage to have a greater availability of water resource compared to the 'Status quo' policy implementation.

Indeed, in figure 11 the total amount of water used in each scenario and under each pricing policy is reported.

The figure shows that only farms k1f1,k2f1,k2f3,k3f1 improve their condition by benefiting from the amount of priority water. These farms use more water than they consume with a regular "status quo" tariff policy during drought. The amount of priority water was not tied to specific clusters, is available to everyone and exchangeable. Therefore, the model assigned the resource to farms with a more rigid water demand curve and where water productivity is higher. Generally speaking, priority water is allocated to farms most willing to pay to mitigate the negative effects associated with the absence of water and reduce exposure to risk.

Figure 12 shows that the reallocation of the resource takes place from farms specialized in annual crops (arable and vegetables) to those farms specialized in permanent crops. For the former, in case of reduced water availability, in the short run, they can update the crop pattern by replacing irrigated crops and / or reducing the irrigated area.

Figure 12 Water use for each water tariff scheme implemented i) Baseline_status quo ii) Drought scenario_status quo iii) Drought scenario_priority.

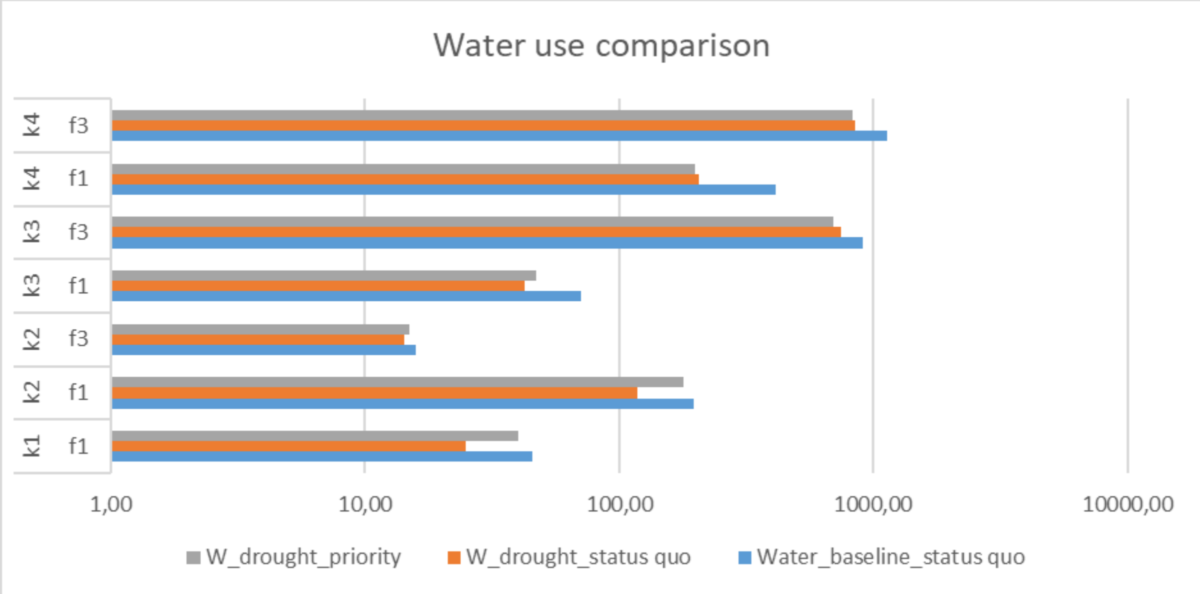


Table 16 reports a direct comparison in terms of GM, Water and Revenue between the policy usually implemented in case of drought (*status quo*) and the proposed alternative one (*priority*).

Table 16 impacts comparison between status quo and alternative priority water pricing policies during drought

Pricing	**Farm**	**GM (1000 €)**	**Water cbc (1000 m^3)**	**Revenue (1000 €)**
Status Quo	K1F1	320.11	24.95	4.49
Priority		335.97	40.03	12.43
Status Quo	K2F1	593.69	118.36	23.71
Priority		672.50	179.41	54.71
Status Quo	K2F3	96.60	4.75	0.85
Priority		97.21	5.43	1.27
Status Quo	K3F1	176.92	42.67	9.49
Priority		179.44	47.35	12.00
Status Quo	K3F3	877.92	249.73	45.70
Priority		880.10	199.79	23.97
Status Quo	K4F1	166.01	206.27	37.19
Priority		168.20	199.65	37.12
Status Quo	K4F3	1421.82	283.50	51.03
Priority		1421.80	258.60	43.11

Data shows a great water resource reallocation between farm typology, leading to economic impact related to priority water tariff more advantageous for all the farms. Indeed, the economic results in terms of GM always show values that are better than or equal to those estimated in the case of the pricing mechanism applied by the consortium (status quo). This situation is well-known as a "Pareto optimality solution" and therefore to be preferred over the current one. With priority water tariff policy, even farms buying less priority (except for k4f3) face lower losses because, unlike the tariff charge implemented by the Consorzio during water scarcity events, the general water sold through the priority water tariff does not undergo any increase.
This is the key aspect of the mechanism: those who receive less water will pay for it a lower price, making the need for a compensation mechanism unnecessary. As data highlight, even if the water resource distribution is strongly oriented towards who can pay more, there is not a condition of "winners" versus "losers" because the economic impacts result to be favorable for everyone (or at most unchanged).

Finally, as regards the last variable of interest (water_self), its quantity does not seem to be influenced by the type of scenario and tariff scheme adopted. This is valid for all the farm types except for k4f3 that is the larger water consumer, and it shows an increase in groundwater overexploitation during drought.
It is reminded that groundwater resource was not granted ad libitum (as usually argued in pre-existing literature).
This could explain the fact that despite the implementation of a tariff scheme that improves the service guarantee in years of drought, farmers continue to use the same amount of groundwater because it is necessary to meet their crops water requirements.
However, although the volumes demanded remain unchanged, a variation in the water resource shadow price is observed. As is known, the shadow price indicates how much the objective function would change with the increase of a marginal unit of the resource. Table 17 reports the different shadow price for farms categories using water_self. What emerges is that for farmers using only self-supplied water irrigation service ("f2") the value remains unchanged. Whereas for farmers adopting both irrigation service ("f3") the variations could be explained by two factors: the reduction in water availability between the baseline and the drought scenario (making the water constraint more stringent and translating in a raising of the shadow price) and the availability of a new water source

(priority water) having a smaller price than water_self 0.20 €/m^3 price of priority water against 0.23 €/m^3 of groundwater). However, it is important to point out that these values are to be considered net of labour costs which have not been taken into account.

Table 17 Shadow price of groundwater for each scenario and water policy implemented

	SHADOW PRICE		
Water policy	Baseline- Status Quo	Drought- Status Quo	Drought-Priority
Farm type			
K1F2	0.40	0.40	0.40
K2F2	EPS	EPS	EPS
K2F3	EPS	0.88	0.50
K3F2	0.45	0.45	0.45
K3F3	EPS	0.22	0.29
K4F3	EPS	0.49	0.50

DISCUSSION AND CONCLUSION

Nowadays, several combined factors including population growth, socio-economics development, increase in high water demand goods (mostly agro-food products) and climate change effects, make the effective and efficient water resources management a relevant issue at international level.

In particular, the Water Framework Directive (WFD), issued in 2000, strongly emphasizes the use of economic instruments, including water pricing, to encourage rational use of water e and ensure adequate costs recovery by all sectors of use, including agriculture.

However, in Italy the type of water pricing scheme and the level of irrigation water cost recovery is poorly harmonized and far to meet the economic and environmental goals as stated in the WFD (Massarutto, 2015).

Another important aspect to consider when designing pricing policies is the impact they may have on the exploitation of alternative water resources.

Indeed, an improper design of the water tariff sometimes translate into an overexploitation of groundwater resource, perceived as less expensive and more reliable (Dono et al., 2010, Giannoccaro et al., 2019).

The debate on the identification of a tariff reflecting the real value of the resource and avoiding distorting effects is open and made even more heated by climate changes that exacerbate of water allocation and service full cost recovery.

Within this context, this Ph.D. thesis aimed to propose a water pricing scheme able to guarantee the full cost recovery even in water scarcity conditions, minimizing the negative effects in a context of conjunctive use of water resource.

Therefore, a positive mathematical programming model that simulate the farmers behaviour in the study area of the Consorzio di Bonifica della capitanata (CBC) was implemented.

The hypothesis was that a priority rule allowing the implementation of security-differentiated water pricing scheme in drought condition, could improve water allocation while ensuring a greater degree of cost recovery and enabling a more efficient risk sharing between farmers.

Moreover, the basic idea was that the proportional rationing methods is not the most suitable in ensuring water allocation, water use efficiency and fairness among farmers.

The results obtained lead us to accept the initial hypothesis that replacing the current water tariff scheme based on the proportional rule with a priority rule based on the service-supply security can help improve water allocation and water cost recovery in the agricultural sector at the territorial (i.e., CBC study area) level.

The analysis of the results, carried out on a small sample of farmers (69) whose irrigated area corresponds to 2% of the total area of the Capitanata, seems to support the design by the CBC of a differentiated pricing policy.

The improve in efficiency involve both farmers' income (Gross Margin) and level of cost recovery (CBC revenue). Indeed, the improvement related to the tariff scheme based on the priority rule corresponds to 2% and 7%, respectively.

These findings encourage the adoption of an alternative water allocation and cost recovery system in case of drought.

According to the neoclassical economic theory, the successful implementation of price discrimination strategy is verified when consumers show different willingness to pay for the same good. Under these circumstances, an enterprise adopting the third-type price discrimination strategy can minimize the reduction in marginal revenues.

In this research this condition was widely verified by observing the water demand curve for each farm analysed. This first result, then translated into aggregate outcomes improvement in terms of Gross margin and Revenue.

To my knowledge the research carried out in in the current thesis is innovative.

Indeed, in Italy the analyses aimed at identifying economic tools to improve the economic and water use efficiency in irrigation sector, have never concerned a modification of the tariff adopted by Consortia based on the heterogeneity of farmers (crop pattern, structural, socio-attitudinal). In fact, the different water demand elasticity has to be taken into account in defining efficient water tariff policies.

In this sense Giannoccaro et al. (2010), Giraldo et al. (2014), and Cortignani et al. (2018), simulate the impact of replacing the existing pricing system of collective irrigation estimating a cost function considering different degree of cost recovery or implementing different water pricing scheme. The authors report that while the improvement in economic efficiency was negligible the negative side effects are relevant and diversified (farmer's income reduction, overexploitation of groundwater, increase in chemical use, negative effects on labour sector). All of these imply the economic axiom of the equal treatment to equals.

Other related work worth noting is the study by Gomez-Limon et al., 2021. These authors also analyse, in an irrigation Spanish district, a water allocation regime with two security-differentiated water rights (high and low priority), which is compared with the proportional allocation rule.

In that case the propose does not concern the water tariff scheme while it focuses on the water rights granted by the water user association. Irrigators could create a portfolio by combining general water rights and priority water rights through an auction procedure that allow the assignation of the priority water right. The total amount of money collected through the auction in order to obtain the priority rights would be saved to compensate all general priority ("losers"). The priority rights once gained lasts forever and this enables a long-term investment planning (i.e. fruit orchards or irrigation technology). In this context, authors show that even if the simulated performance could generate a small efficiency improvement, the economic gains is not enough (0.02% increase) to cover the implementation costs associated with the implementation of the proposed allocation regime.

A possible explanation for this small result may be related to the low heterogeneity characterizing the irrigated crop pattern simulated. Indeed, the farm type identified by Gomez-Limon et al., 2021 mostly differ in size, however, the irrigated crop pattern is almost the similar. In this way, even if the clusters show a different water productivity, the willingness to pay for the resource could be the same leading the implementation water rights security differentiated unsuccessful.

Although the objectives of the work are similar to those addressed in this thesis, however, in the current case the intervention can be considered more flexible and easily to be implemented in the short run. In our case the modification does not involve a structural modification of the rights imposed by the consortium. If on the one hand the compensation mechanism is absent, on the other hand this intervention is limited to acting only in case of drought events. In this thesis there is no auction mechanism and the transaction costs to implement the reform will be smaller. This implies that even if the increase in overall economic outcome is not so high, it can be considered a valid tool to mitigate the negative effects of drought events in the short term both for farmers (who can better share the risk faced) and for the consortium (that could slightly increase its revenue).

In conclusion, in the context of climate change, where farmers need to stabilize their income and Consortia are called to be more efficient in cost recovery both study share that differentiated priority rights or by applying a water tariff price discriminated represents a valid adaptation instrument.

However, the research requires further refinements in order to extend the research and obtain more accurate results. In this sense, since the price of priority water has been set up a priori by researcher (respecting the hypothesis that higher security level corresponds higher price than general water) probably the price set does not reflect the marginal value of the resource. Further research could provide for the parametrization of the priority water price and analyse the new impacts.

Moreover the model optimizes the objective function of the sample at territorial level using the farm as unit of investigation. Assessing the impact of water priority tariff at the basin level, incorporating weights for each farm represented, could provide relevant new insights into this topic.

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