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Research article

Economic analysis of irrigation services. An application of the hedonic price method on the FADN data

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Abstract. The economic valuation of water uses, as the Water Framework Directive (EC/60/2000) suggests, should support policymakers in water management. Aiming to assess the economic value of irrigation water services, a hedonic price analysis was conducted on the value of farmland. Specifically, we examined the differences between collective and self-supply irrigation services, with the hypothesis that each reflects different water supply qualities that are capitalized into land value. A homogeneous sample of olive farms in the Apulia region was analysed using data from the Farm Accountancy Data Network. The results confirm the hypothesis that different economic values are assigned to water services. A higher value of self-supply service with respect to collective ones might be associated with the greater security and reliability of the service provided. Finally, our analysis points out that the Farm Accountancy Data Network database can provide policymakers with a harmonized dataset for the economic evaluation of irrigation water. This can help them to develop evidence-based policies, as required in the Water Framework Directive.

Keywords: water economics, irrigation, water service valuation, Farm Accountancy Data Network, olive grove.
JEL codes: Q15, Q25.

HIGHLIGHTS

- Collective and self-supply water services have a different impact on the value of farmland.
- Hedonic analysis on the value of irrigated land reveals the higher value of self-supply service compared to collective service.
- FADN database provides the basis of a common dataset for the economic evaluation of irrigation water.

1. INTRODUCTION

In recent years, the focus on the sustainable management of water resources has increased as a result of the pressure exerted by increased withdrawals. Moreover, the reduced availability of water resources is countered by the variability of the quantity of water due to climate change (Raggi *et al.*, 2008). From a regulatory standpoint, the Water Framework Directive (WFD) (EC/60/2000) drew the attention of the European community to the need to strengthen economic valuation tools, acknowledging their importance for efficient management and allocation in a situation of scarcity and uncertainty. The economic analysis of water uses lays the foundations to achieve a twofold objective: on the one hand, it is configured as a cognitive element to support policymakers, representing both a regulatory obligation for the drafting of a Water Master Plan at the basin scale and an indication of the condition of scarcity of the resource. Therefore, it should be at the basis of choices regarding the allocation rules among competitive uses. On the other hand, the economic analysis should steer Water Authorities to define tariffs capable of recovering the "full cost" associated with the use of the resource.

However, it is important to specify that water as a good in agriculture, and likewise in the civil and industrial setting, does not exist as such but is always associated with the concept of water services. In agriculture, the general distribution of irrigation resources is divided into two service categories: i) collective water service and ii) self-supply water service. In the first case, the irrigation provider organizations, which in Italy are mostly represented by the Land Reclamation and Irrigation Consortia (*Consorzi di Bonifica e Irrigazione*), deal with distribution and allocation (i.e., who has access, for what use, and in what volume). The service offered by the consortia has characteristics linked to the delivery mode: i) rotating delivery, ii) on demand, iii) continuous operation, iv) with reservation, v) under pressure. In the second case, the self-supply service ensures the demand for water through a different modality, according to which farmers can draw the resource on their farm or close by and, mostly relevant, when needed (i.e., on-demand). However, all the costs (both for the initial investment and operational) for the sourcing, catchment and distribution of the resource are borne by the farmer. In addition, access to water sources is issued by licensing that can be charged with fees as documented in some European Member States (Berbel *et al.*, 2019).

Some scientific papers available in the literature argue that the self-supply service from groundwater is associated with a rather low pumping cost, making it a valid alternative or supplementary source to the collective service that generally uses surface water (Giordano *et al.*, 2007; Ross, Martinez-Santos 2010; Sardaro *et al.*, 2020). In addition, the feeling of forced control over withdrawals generally exercised in cases of collective service appears to fade (Kahil *et al.*, 2016). There is a growing theory however that the advantage associated with a self-supply irrigation service, rather than being related to a lower cost (which varies depending on factors such as technology, depth of the aquifer, as well as regional specifications regarding concession fees), is related to the security and guarantee of supply that could make it qualitatively better and more highly appreciated than the collective service (Mesa-Jurado *et al.*, 2012; Giannoccaro *et al.*, 2019; Mirra *et al.*, 2021). In a context of climate change that produces strongly altered hydrological and rainfall regimes, the quality of the irrigation water service becomes more important, translating into an adequate guarantee of resource provision (Rigby *et al.*, 2010; Giannoccaro *et al.*, 2019; Fernández García *et al.*, 2020). Furthermore, at a time when smart irrigation, digital irrigation and precision farming represent the most advanced solutions to achieve the objectives of sustainability in agriculture, a timely, reliable and secure water service becomes a worthy requisite to save irrigation water. Although irrigation advisory services can release valuable irrigation-related information to farmers (Altobelli *et al.*, 2021; Galioto *et al.*, 2017), the potential for water saving will vanish with poor quality-of-service delivery (e.g., if delivery scheduling is longer than advised watering time).

Given the premise, the objective of this study is the economic evaluation of irrigation water services, the characteristics of which constitute a major factor in determining the success of the practice. Specifically, the study aims to estimate the economic value of the two types of water services commonly adopted in the Italian irrigation sector: collective vs. self-supply. The hypothesis underlying this research question is that each type of service expresses different qualitative characteristics of water supply and that these are valued by the operators.

While the economic benefits of irrigation water have been largely investigated (see Young, Loomis (2014) for a review), few scientific works have so far recognised the importance of the type of service adopted in determining the economic value of the irrigation water (Joshi *et al.*, 2017; Mirra *et al.*, 2021). In the absence of a competitive market, such as in the case of irrigation water, the economic valuation of irrigation services can be indirectly estimated. Previous literature showed that the value of irrigation intrinsically influences the value of land, which is an asset in a well-defined market (Young, Loomis, 2014). It may be linked to the fact that irrigation increases the productivity of land (Ruberto *et al.*, 2021) and the range of possible land uses (Gioia *et al.*, 2012) and allows the stabilization of quality productions, reducing the fluctuations in yields and consequently of agricultural incomes (Giannoccaro *et al.*, 2016).

Therefore, to answer the research question, a hedonistic evaluation was conducted (Taylor, 2003; Freeman III, 2021) on the value of agricultural land. The hedonic price method (HPM) suggests that variations in the economic value of agricultural land are influenced by each attribute or characteristic of the land, such as access to irrigation water or volume of water (Young, Loomis, 2014). With reference to the Italian context, examples of the valuation of irrigation resources can be found in Mirra *et al.* (2021), Rosato *et al.* (2021), and Tempesta *et al.* (2021), among others. Although in these studies the HPM is commonly applied to the land value, the source of the dataset used is different. In Mirra *et al.* (2021), monetary value for land was gathered by surveying landholders. They collected self-reported values of the likely market price for land owned by interviewees, also called "asking price", which is the price suggested by a seller but usually considered to be subject to bargaining. The main shortcoming of direct interviews with landholders is the high cost associated with gathering land value, which refers to a value at a point in time. Average Agricultural Value[1] has been used by Rosato *et al.* (2021). Despite being easily accessible, the validity of the criterion adopted to determine the Average Agricultural Value and its appropriateness to estimate the value of an asset remains controversial (Marone, 2008; Gioia *et al.*, 2012). Most importantly, for an accurate economic analysis of water use in agriculture, some relevant variables, such as type of service and irrigated volume, are not available when using the Average Agricultural Value. In the absence of the water quantity for the individual land observations, the approach is termed "quasi-hedonic" (Berbel *et al.*, 2007). In Tempesta *et al.* (2021), real transactions on the farmland market are scrutinised to gather land values. The major limitation of an HPM application on farmland refers to a lack of a competitive land market on which land prices are generated (Schimmenti *et al.*, 2013), as well as the lack of a sufficient number of transactions.

In order to test the research hypothesis, an econometric analysis was conducted on the value of agricultural land in a pilot area appropriately chosen for crop homogeneity, farm characteristics, and presence of multiple irrigation services, i.e., collective vs. self-supply from underground aquifer. The survey area falls within the Apulia region and corresponds to an area of greatest specialisation in irrigated olive trees. Agricultural land values were obtained from the database of the Farm Accountancy Data Network (FADN). In this context, a further innovative element of this research was to explore the potential of the FADN dataset as a valid support in the economic analysis of water use in agriculture. To do so, we also checked for the robustness of the land value reported in the accounting sheet of FADN's dataset and whether it can reveal the value of services for irrigation. To the best knowledge of the authors, this study is the first attempt to conduct an economic analysis of irrigation water using the FADN land values.

The research presents a description of the regional context on which the analysis is focused, a description of the observations of the analysed sample, and a section dedicated to the methodology used for the economic evaluation. Then, in the results section, the main descriptive analyses conducted will be discussed and the findings of econometric models shown. Finally, the last two paragraphs are dedicated to a discussion of the results obtained and the conclusions of the study, including future implications.

2. MATERIALS AND METHODS

2.1. The regional context of study area

The Apulia region is characterised by a strong agricultural vocation, with a total of 191,430 farms throughout the region, based on ISTAT agricultural census data (ISTAT, 2020). The production orientation characterising the territory sees olive cultivation as most prevalent, involving 160,080 farms. According to the census data, among the agrarian permanent crops, the olive tree is the most widespread and influences the distribution of agrarian permanent crops in Southern Italy, representing 71% of the surface area cultivated with agrarian permanent crops in Apulia. In this region, the water resource plays an important role in determining the technical-economic specialisation: indeed, the olive tree is the most widespread irrigated crop, followed by the wine grape, together accounting for 61% of the irrigated area in Apulia (Giannoccaro *et al.*, 2020).

Apulia is a region with poor surface water streams (with the exception of the Ofanto and Fortore), so it depends on other neighbouring regions to meet its irrigation water needs, which are met through interregional schemes. The organisation of the water service is of two types: collective distribution, under the respon-

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[1] Average Agricultural Value (Valore Agricolo Medio) of the farmland carried out by the provincial commissions, established pursuant to Article 41 of the Presidential Decree of 08/06/2001 No. 327, to determine the compensation for expropriation for public utility.

sibility of the various Land Reclamation and Irrigation Consortia in the territory, and self-supply service, i.e., mainly individual users with an authorisation to use water for irrigation purposes. Collective distribution is managed by six consortia operating in the territory. The consortium structures are supplemented by the collective networks managed by the Regional Agency for Irrigation and Forests (ARIF). As far as individual users are concerned, this phenomenon has a significant size and constitutes 65% of regional irrigation (Giannoccaro *et al*., 2020). However, the region is characterised by striking differences across the provinces. Foggia, for example, achieves the highest share of irrigated land serviced by collectively delivered surface water (50%), while for Lecce almost 80% of the total is served by on-farm abstraction of groundwater. The average irrigation volume for Apulia is estimated at 655 million m^3 (Lupia *et al*., 2013), however, groundwater abstraction increases considerably in periods of severe drought (Portoghese *et al*., 2021).

In order to obtain a sample of farm observations that would be homogeneous in terms of structural characteristics, cultivation system and location, the study area of interest was identified as the area of greatest irrigated olive-growing specialisation in the Apulia region (Figure 1). Olive groves also show a uniform adoption of on-farm drip irrigation systems. With respect to structural and cultivation homogeneity, the study area reflects the infrastructural heterogeneity of Apulia's irrigation service. Indeed, there is a coexistence between the collective service offered by the Capitanata and Terre d'Apulia Land Reclamation and Irrigation Consortia and the self-supply service from the groundwater.

2.2. FADN dataset and description of the sample

The total of olive groves located in the area of interest was extracted from the FADN database, considering farms with at least 0.5 ha of olive grove area to avoid the presence of outliers. As a whole, a sample of 63 farms was

Figure 1. Map of the rivers, streams, public waters and the equipped area of collective irrigation network across the survey area.

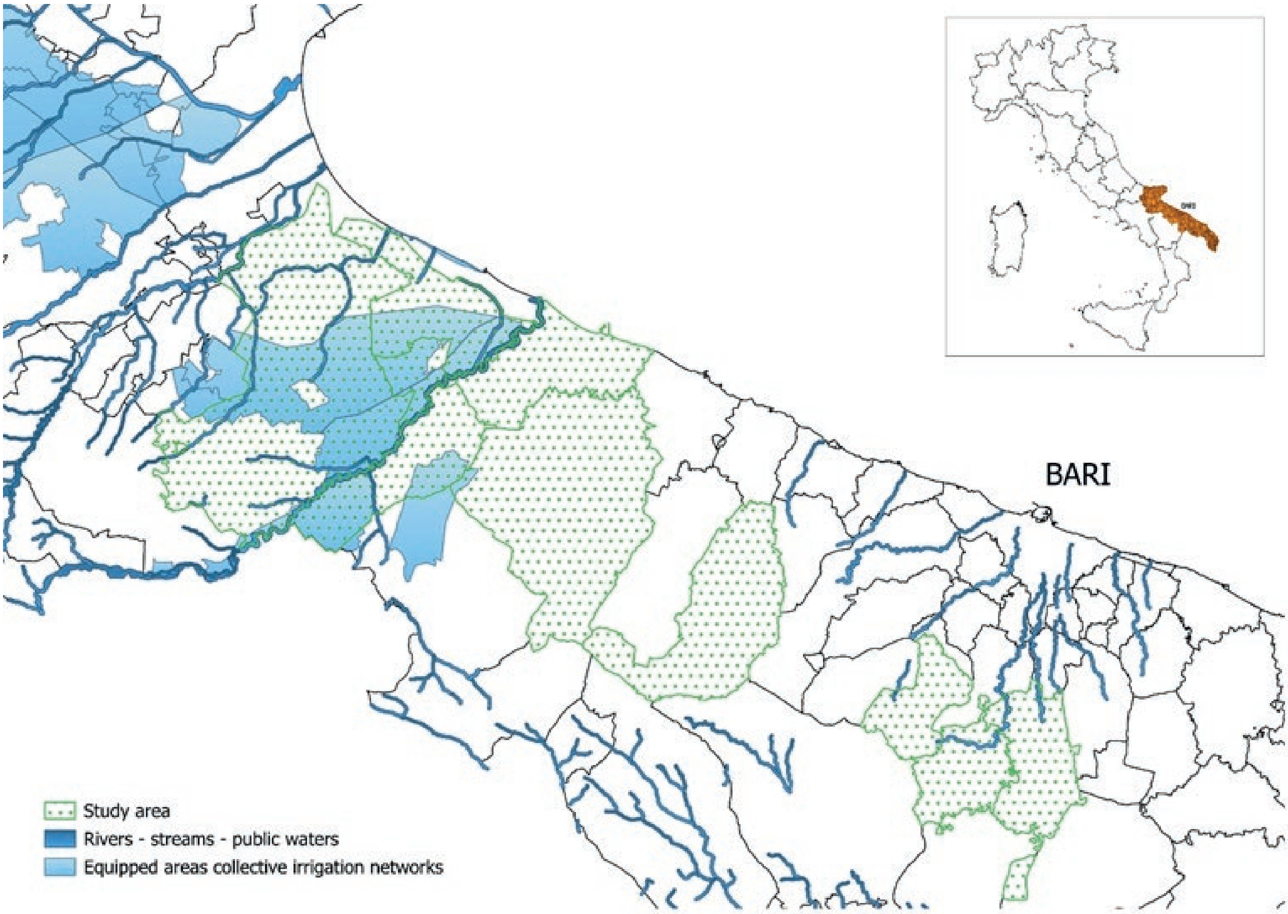

Table 1. Description of variables and relative descriptive statistics.

Variable	Description	Mean	Std. Dev.
Land value	Bare land value expressed in thousands of euros per hectare	28,282	11,406
Collective service	Availability of consortium service (1= if yes; 0= otherwise)	0.48	0.50
Self-supply service	Adoption of self-supply service (1= if yes; 0= otherwise)	0.36	0.48
Irrigated surface	Irrigated hectares	2.91	3.86
Volumes*	Volumes irrigated in cubic metres per hectare	1,420	655.83
Plant density	Number of plants per hectare (0= less than 100; 1= greater than 100)	0.60	0.49
Slope	Type of slope (0= flat; 1= steep)	0.09	0.28
Altitude	Altitude in metres above sea level	112.34	106.70

*Note: The information on irrigation volumes is recorded in the FADN dataset at crop level; for this study they have been derived at the specific plot level by average calculation in relation to plot area.
Source: own elaboration of FADN data.

retrieved, while the dataset gathered consists of 169 observations of land plots[2], recorded from 2016 to 2019. Following the removal of duplicate observations made for the same land plot over time, the observations create a pooled dataset that measures a distinct land value for each plot.

Broadly speaking, the FADN database provides information on various aspects of agricultural production, collected at different farm levels such as whole farm, specific crop and land plot. Hence, in accordance with the aim of the research, we included in the sample the variables that are strictly collected at the plot level. Table 1 shows the descriptive statistics of the variables included in the sample. The variable "land value" is contained in the land section of the FADN database and shows the value of the bare land estimated according to the criterion of most probable market value (Povellato, 1997; Gioia *et al.*, 2012). The estimation is performed by taking the portions of farmland on which condition of homogeneity occurs with respect to the main variables affecting the value of the land itself (Gioia *et al.*, 2012). Namely, the land value is linked to altitude, land features (e.g., slope), and land improvements (buildings and stable plants, agricultural hydraulic equipment, etc.) (Povellato, 1997). The FADN data is based on the separate estimation of the value of bare land and the value of plantations such as olive groves or other permanent crops. An inflationary update to 2019 was carried out on these monetary values by using the agricultural land prices index published by Eurostat[3].

The variables relating to the type of irrigation service, planting density and location have been coded as binary variables. Specifically, the variable "collective service" refers to the availability and, consequently, access to the irrigation service managed by the Land Reclamation and Irrigation Consortia. That is, 48% of the sample observations are provided by collective service. The "self-supply" variable, instead, includes observations relating to farms that have access to the resource through private self-supply infrastructures (36%), while the remaining 16% do not have access to any irrigation service. Regarding the variables relating to the use of water resources, the average irrigated area is 2.91 hectares, and the annual irrigation volumes average 1,420 m^3 per hectare. As far as plant density is concerned, we can state that 60% of the olive groves on the farms in the sample analysed have a plant density with a number of trees per hectare of more than 100. This threshold can be considered the value below which one is in the presence of extensive and traditional types of cultivation systems. The variable "altitude" indicates that the land owned by the farms is located in a predominantly lowland area, with an average altitude value of approximately 112 metres above sea level. In addition, the variable "slope" describes the slope of the land with respect to the horizontal plane and indicates that only 9% of the examined observations have a land inclination between 5 and 20%.

2.3. Methodology

To conduct this study we used the HPM, which is based on the feature value theory originally proposed by Lancaster (1966). The HPM states that any good can be described as a set of characteristics and the levels these take on and that the price of the good depends on these characteristics and their respective levels (Birol *et al.*,

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[2] The plot is defined as a portion of land, even if not continuous, with uniform potential and physical-productive characteristics and mainly intended for homogeneous use (same type of cultivation), with the same title of ownership, with the same pedological characteristics (altitude, position and texture), the surface area of which is located in the same municipality.

[3] The index was calculated using the agricultural land prices index calculated at the regional level, which is available on the Eurostat website at https://ec.europa.eu/eurostat/data/database.

2006). According to the theory that proposes this methodology of analysis, the value of an asset (in this case agricultural land) can be attributed to a vector of *n* characteristics through a direct and functional relation (Lancaster, 1966; Rosen, 1974; Hanley, MacMillan, 2008). The chosen methodology proposes a hedonic analysis aimed at evaluating the water resource for irrigation purposes, under the assumption that a higher economic value can be associated with land with irrigation service access. Since irrigation is a practice that increases the productivity of agriculture (Ruberto *et al.*, 2021), the increase in revenue from this practice can be capitalised in the land value (Giannoccaro *et al.*, 2016). Furthermore, a higher economic value can be associated with self-supply service with the capacity to act as a reliable water service for irrigation, providing water on demand.

In mathematical terms, we can express the relation between the value of the land and its *n* characteristics through an econometric regression such as:

$$p_l = f(x_{l1} + x_{l2} \ldots + x_{ln}) \tag{1}$$

where p_l denotes the value of land, and x_{ln} is the vector of each characteristic associated with the land value. Economic theory imposes no constraints on the form of the hedonic price function (Palmquist, 1989) as a consequence the choice of this form must be determined empirically and correctly interpreted as an approximation of the true hedonic price function (Garrod, 1999). Indeed, among the most widely-used regression models (i.e., linear, log-log, log-linear and linear-logarithmic), the one that best fits the available data is the log-linear one, which is also confirmed performing the Box-Cox test:

$$ln(Y_i) = \beta_0 + \beta_n X_n + \varepsilon, \tag{2}$$

where Y_i, the dependent variable, is the value of land per hectare expressed in Euro, X_n is the vector of explanatory variables, β_n forms the set of respective parameters to be estimated, ε is the residual obtained from the estimation of the regression model, while β_0 is the estimated parameter referring to the constant (intercept). The econometric model was estimated using the ordinary least squares (OLS) method.

Based on the data available at plot level (Table 1), equation 2 was estimated. In addition, with the aim of investigating the potential endogeneity bias (Moore *et al.*, 2020) in the hedonic estimates, two different model specifications were implemented. The decision to implement two different econometric models was driven by the strong influence that the altitude variable may have on the other explanatory variables (i.e., water services, slope and irrigated surface). Therefore, the first model differs from the second only in the presence of the altitude variable.

The estimated hedonic equation for the first model was specified as:

$$\begin{aligned}\ln(\textit{land value}) &= \beta_0 + \beta_1(\textit{collective service}) + \beta_2(\textit{self-supply service}) + \beta_3(\textit{irrigated surface}) + \beta_4(\textit{volumes}) \\ &+ \beta_5(\textit{plant density}) + \beta_6(\textit{slope}) + \beta_7(\textit{altitude}) + \varepsilon\end{aligned} \tag{3}$$

where the value of the land is expressed as a function of its characteristics, such as irrigation service (collective or self-supply), irrigated area, irrigated volumes, plant density, slope and altitude.

The estimated hedonic equation for the second model was specified as:

$$\begin{aligned}\ln(\textit{land value}) &= \beta_0 + \beta_1(\textit{collective service}) + \beta_2(\textit{self-supply service}) + \beta_3(\textit{irrigated surface}) + \beta_4(\textit{volumes}) \\ &+ \beta_5(\textit{plant density}) + \beta_6(\textit{slope}) + \varepsilon\end{aligned} \tag{4}$$

3. RESULTS

3.1. Analysis of water-related descriptive statistics

A preliminary analysis was conducted to verify the characteristics of the entire sample. Firstly, we examined the variation in the averages of the value of the land in relation to the type of service adopted with the aim of verifying the presence of a difference in monetary terms of the land between the two irrigation services. This difference is attributable to intrinsic characteristics of the service. The results (Table 2) report an average value per hectare of approximately 29 thousand euro for land accessed to the collective service (therefore served by consortia), while the observations concerning land on which there is a groundwater self-supply infrastructure report a slightly higher average value of approximately 34 thousand euro per hectare. As expected, the lowest average is reported for land that does not have access to irrigation water (approximately 12 thousand euro per hectare).

The Kruskal-Wallis test was used to determine the existence of a statistically significant difference between the medians of three or more independent groups. This test is the non-parametric equivalent of one-way ANOVA and is typically used when the assumption of normality is violated, i.e., it does not assume the normality of the data and is less sensitive to outliers than the one-way ANOVA. The p-value resulting from the test confirms a statistical difference between the groups considered, stating that at least one group differs. Generally, if the results of the Kruskal-Wallis test are statistically

Table 2. Land plot value based on irrigation service accessed.

Irrigation service	No. obs.	Mean value (euro/ha)	Std. Dev.
absent	26	12,327 ^{a}	2,490
collective	82	29,269 ^{b}	7,640
self-supply	61	33,756 ^{c}	11,866
Kruskal-Wallis test			*p-value* = 0.001

Note: numbers followed by different letters are statistically different at p > 0.1%
Source: own elaboration of FADN data.

Table 3. Volumes (m^3/ha) used based on irrigation service accessed.

Irrigation service	No. obs.	Mean volume (m^3/ha)	Std. Dev.
collective	82	1,479 ^{a}	614
self-supply	61	1,342 ^{a}	706
Two-sample *t-test*		t = -1.24	*p-value* = 0.217

Note: numbers followed by different letters are statistically different at p > 0.1%.
Source: own elaboration of FADN data.

significant, it is appropriate to determine via Dunn's test exactly which groups differ. In this case, the statistically significant values indicate that all groups differ from each other, so it can be asserted that the land value appears to be different for all three groups. In particular, the results of the test show a substantial difference in the land value of rainfed land compared to irrigated land but a higher value for land served by self-supply than for land served by collective networks.

With the aim of investigating the causes that would potentially influence this statistical difference, two hypotheses were formulated accordingly: in the first case, the adoption of one type of service with respect to another may depend on the volume of water used; in the second case, investigating the presence or absence of economies of scale, we verified whether the average irrigated surface area differs based on the irrigation service adopted.

Regarding the first hypothesis, as can be seen from the data shown in Table 3, the average volumes (m^3/ha per year) used are almost similar between the two types of service. Based on the t-test results, there is no statistical evidence to reject the null hypothesis, indicating that the average volumes of water used do not significantly differ based on the type of irrigation accessed.

Finally, from the data in Table 4, we highlight that the difference in the average irrigated area between the consortium service and self-supply service, as suggested by the Wilcoxon test, is not significant according to which the mean of cultivated land does not statistically differ according to the water service accessed.

Data reveal differences in the land plot value based on irrigation service accessed while the usage volume and extent of irrigated land is randomly distributed among the two services.

3.2. Econometric model

Following the methodology described above, the results of the hedonic model are shown in Table 5. Model 1 includes all independent variables, while Model 2 does not include the altitude variable to account for potential endogeneity bias caused by the correlation between altitude and other variables.

Table 4. Irrigated surfaces (ha) compared to irrigation service accessed.

Irrigation service	No. obs.	Mean surfaces (ha)	Std. Dev.
collective	82	3.4 ^{a}	4.6
self-supply	61	2.2 ^{a}	2.4
Two-sample *Wilcoxon test*			z = -1.52 *p-value* = 0.128

Note: numbers followed by different letters are statistically different at p > 0.1%.
Source: own elaboration of FADN data.

In both models, all beta coefficients of the variables have the expected sign while their statistical significance changes significantly. Overall, the first model has a much higher degree of fit to the data, R^2 equal to 0.78, indicating that 78% of the variations in land values are explained by the model. In the second model, however, the degree of fit R^2 to the data is 0.53, indicating that the estimated model fits the data quite well and is therefore considered useful in explaining the relationship between the variables.

In general, as regards the goodness of fit of the different model specifications, the F-statistic and Root Mean Square Error (RMSE) assess that Model 1 fits the estimated relationship well. In Model 1, the F-statistic is higher (81.05 > 30.32), and the RMSE is lower (0.22 < 0.32) compared to Model 2. Moreover, regression diagnostics were carried out on multicollinearity (variance inflation factor – VIF). The VIF values exclude predictor collinearity problems because they are lower than the thresholds frequently utilized by analysts (Snee, 1973; Marquandt, 1980). In model 1, the VIF values referring to the water services are comprised of between 5 and 10, indicating a moderate correlation between these vari-

Table 5. Regression models

	Model 1		Model 2	
	Coeff.	*St. Err.*	*Coeff.*	*St. Err.*
Collective service	0.1499*	0.8607	0.7779***	0.1054
Self-supply service	0.1798**	0.0871	0.8807***	0.1018
Irrigated surface	-0.0039	0.0057	0.0054	0.0082
Volumes	-0.0001***	0.0001	-0.0001	0.0001
Plant density	0.1021**	0.0421	0.1630***	0.0609
Slope	-0.1283**	0.0623	-0.0755	0.0904
Altitude	-0.0035***	0.0003	--	--
Cons	10.4647***	0.0939	9.3687***	0.0687
No. Obs.	169		169	
F-statistic	F (7, 161) = 81.05		F (6,162) = 30.32	
Prob > F	0.0000		0.0000	
R-squared	0.7790		0.5290	
Adj R-squared	0.7694		0.5115	
Root MSE	0.2204		0.3207	
Mean VIF water services	6.26		4.24	

Note: Asterisks (***), (**) and (*) indicate significance at 1%, 5%, and 10% respectively.
Source: own elaboration of FADN data.

Table 6. Exponential transformation of coefficients.

	Model 1		Model 2	
	Coeff.	e^{β} - 1	Coeff.	e^{β} - 1
Collective service	0.1499*	0.1617	0.7779***	1.1769
Self-supply	0.1798**	0.1970	0.8807***	1.4125
Plant density	0.1021**	0.1074	0.1630***	0.1770
Slope	-0.1283**	-0.1204	-0.0755	-0.7268

Source: own elaboration of FADN data.

ables and other predictors. In model 2, instead, the VIF that refers to the variables included in the model is less than 5, indicating a lower correlation among regressors.

Regarding the statistical significance of the estimated coefficients, in the first model the explanatory variables are all statistically significant, except for the irrigated area. In this case we noted that the altitude variable (continuous, expressed in metres above sea level) strongly influences the relationship between the explanatory variables and dependent variable, with negative changes in the value of land as it increases. In the second model, the significant variables are the dummies relating to the type of service adopted and the plant density. Moreover, in both models, it is worth noting that the intercept value is highly significant and of a large magnitude, a sign that there is, in general, a base value for agricultural land in the area.

Since a semi-logarithmic form of regression was used, the estimated β would represent the impact on the logarithm of the dependent variable. In order to obtain the effect that a percentage change in the independent variable has on land value, a further transformation of the dummy variables was required, which included the calculation of e^{β}-1. The results are shown in Table 6.

The coefficient of an explanatory variable of a dichotomous type expresses the percentage change attributable to the presence of a certain quality attribute, all other conditions being equal. Therefore, in the first model, our estimates reveal that the case of land provided by water services reports a higher land value compared to rainfed land (16% for land with collective service and 20% for land with private self-supply infrastructure). However, the beta comparison test of the two different services conducted on this model does not show a difference in the land value of the two services in statistical terms, given a p-value equal to 0.44. Moving from a lower density of one hundred plants per hectare to a higher one, the land value undergoes a positive change of 11%, while moving from flat land to land with a steeper slope, the value undergoes a change of -12%.

From the second model, it can be inferred that the variables influencing the value of land are those related to the type of service and plant density. Thus, all other things being equal, the value of land under a collective supply system differs by 117% compared to rainfed land. Furthermore, the value differs by 141% in the presence of private self-supply systems. The beta comparison test of the two different services has confirmed for this model, given a p-value of 0.07, a difference in the land value of the two services in statistical terms. The plant density variable explains how the land value changes by +17% when the number of plants per hectare is greater than 100. The other variables are not significant.

4. DISCUSSIONS

The results confirmed the hypothesis that the value of land provided with a self-supply water service is statistically different from and higher than the value of land provided with a collective water service. The application of the HPM made it possible to disaggregate the value of land for each attribute, recognising that a self-supply service has a greater capacity to contribute to the value of land in monetary terms. The result is in line with other works in the literature that have seen the need to adapt the strand of analysis on the economic value of irrigation to climate change. As demonstrated by Joshi *et al.* (2017), the value of land is influenced not only by the presence or absence of irrigation water but also by the type of infrastructure and service that facilitates its utilization. Also Mirra *et al.* (2021), through self-reported land values by farmers show that in the long run, a higher value associated with self-supply irrigation service is capitalised in the buy-sell price of the land. The hypothesis common to these works is that the increased security and reliability associated with the farmer-managed service is reflected in its unit value, acknowledging these attributes as having a positive economic value.

The use of a sample as homogeneous as possible by limiting the analysis to a specialised olive grove area partly justifies the modest difference, in terms of economic value, between the two services. In fact, the olive tree is a crop that can also be grown in conditions of limited availability of water resources (controlled water deficit), an aspect that mitigates the difference in absolute value compared to what would happen if one were to consider a particularly water-demanding crop (e.g., processing tomatoes and fresh-cut vegetables) for which timeliness and security in the distribution of the resource are essential characteristics (Giannoccaro *et al.*, 2019).

Another fundamental aspect to be considered in the interpretation of the results concerns the altitude variable, which is such a determinant factor in defining the land value that it is included as an explanatory variable in the majority of hedonic regression models conducted to date (Giannoccaro *et al.*, 2016; Sardaro *et al.*, 2020; Rosato *et al.*, 2021; Tempesta *et al.*, 2021). The altitude of a land plot significantly influences numerous factors such as soil productivity, distance from a built-up area, the possibility of mechanisation of agricultural processes as well as access to water resources (e.g., depth of well). However, from a methodological point of view, this influence is reflected in the presence of endogeneity, a well-known factor distorting the estimates made using OLS regression models (Moore *et al.*, 2020). This aspect emerges clearly when we compare the results of the two models shown in Table 5. Indeed, the estimated coefficients related to water services differed greatly. This is related to the high correlation of altitude with other independent variables (e.g., water services adoption and altitude are highly correlated), even though the inclusion of altitude in Model 1 improves the estimates as a whole. In a recent work, multiple correspondence models have been identified as a way to overcome this limitation (Tavares *et al.*, 2022). Despite the highlighted limitations, the model can be considered to be good compared to models conducted to date in the Italian scientific literature (Mazzocchi *et al.*, 2019; Rosato *et al.*, 2021), as it achieves an R^2 value well above the minimum acceptable threshold defined by Hair *et al.* (2019).

Finally, the aspect that most emphasises the potential of our experiment in comparison to the pre-existing literature concerns the nature of the data used. In fact, the authors that have so far attempted to assess the water resource by means of hedonic estimates have mostly employed data collected through direct surveys (Latinopoulos *et al.*, 2004; Schlenker *et al.*, 2007; Giannoccaro *et al.*, 2016; Mirra *et al.*, 2021) with the self-reporting technique, for which the large margin of approximation often observed with respect to land values is well known. In contrast, other authors have employed land registry data, and regional and/or provincial databases (Pirani *et al.*, 2016; Mazzocchi *et al.*, 2019). Rosato *et al.* (2021), in an attempt to use a uniform dataset on a provincial scale, used the database of Average Agricultural Values made available by the dispossessions office. However, Average Agricultural Values struggle to take into account on-farm water volume and, most relevantly, irrigation services.

Compared to the previously-mentioned literature, we opted to use the FADN database, which has the benefit of accurately approximating the real values of land plots with a set of specific characteristics (e.g., altitude, slope, etc.), in addition to the type of service and irrigation volume. Additionally, the availability of FADN data, for the whole country and in homogeneous form, highlights its potential in representing the reference as a database for the economic evaluation of irrigation water. However, some relevant variables that affect land value, such as plot access to the main road or distance from the city centre (see Sardaro *et al.*, 2020) are not available in the FADN dataset.

5. CONCLUSIONS

This work aligns with the ongoing debate regarding the economic evaluation of water resources in agriculture. The article analysed how water services affect the land value of olive farmland in the Apulia region through the estimation of an HPM. More specifically, we investigated whether the collective and self-supply services might have a different impact on the value of farmland. Similar to previous research, our findings show that irrigation increases the value of land. Additionally, we found that self-supply service has a higher impact compared to collective ones. While there is no difference in the applied volume, the higher value of self-supply service may be related to the aspect of promptness, security, and guarantee of supply of the resource.

Our findings have several policy implications. One of the main ones is that consortia should improve the quality of service in terms of timeliness. Even though an advisory irrigation service can enhance water saving, uneven patterns of scheduling or unreliable water supply of a collective service can frustrate farmers' decisions. Otherwise, a collective service should try to introduce a price-differentiation mechanism according to the reliability of water delivery as recently proposed by Mirra *et al.* (2023).

Despite the limitations of the data collected, the research highlights the potential of the FADN dataset in supporting the possibility of making systematic use of a uniform dataset on a regional and national scale, which would allow progress in the previously undertaken path of data harmonisation on agricultural irrigation. It is definitely a priority at the national level, where the economic evaluation of the resource for irrigation use appears to be not homogeneous.

Nevertheless, the study is not free of limitations. Firstly, we confined our analysis to a small sample of farms located in a homogeneous area and growing the same crop. Therefore, the analysis should be conducted at least at a regional level, considering all crops, to better support the economic analysis of water uses in the Water Master Plan. Another important limitation, from a methodological point of view, is related to the need to identify an econometric model that would allow for the inclusion of a relevant variable in the determination of the value of land, such as altitude. At the same time consideration should be given to the endogeneity issues that arise, given the relationship that altitude has with other variables. Lastly, as regards the FADN data, the possibility should be considered of collecting other relevant information at plot level (i.e., water quality and cost for irrigation) to go in-depth into the economic evaluation of irrigation water. However, the results of the estimated model can still be considered robust due to the detailed information collected at plot level by the Italian data collection system.

In light of the findings of this research it is worth noting that, during a period where the uncertainty caused by climate change prominently threatens agricultural production in both quantitative and qualitative terms, the aspect of security and guarantee of supply of the resource cannot be neglected when identifying the economic value of the distribution service of the resource. Therefore, future research should take heterogeneity into account due to the different water services in the evaluation of water resources.

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AUTHOR CONTRIBUTIONS

Conceptualization, E.T. and G.G.; Methodology, E.T., L.M., S.R. and G.G.; Data gathering: G.V. and D.C; Software: E.T. and S.R.; Validation: E.T., L.M., S.R. and G.G.; Formal analysis: E.T., L.M. and S.R.; Data curation: E.T.; L.M. and S.R.; Writing – Original Draft, E.T. and L.M.; Writing –Review & Editing, L.M., S.R., G.V., D.C. and G.G.; Visualization: E.T.; Supervision, G.G. and G.V; Funding Acquisition, G.G.

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