Water Losses and Maintenance Investment. An Econometric Model for the Sustainable Management of Water Services

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Abstract. In Italy, there is a large gap between the water supplied to the distribution networks and the water delivered to users. Reducing the dispersion along the aqueduct network has several advantages for water service operators, such as reducing the production and distribution costs of the resource, limiting the volumes of water purchased wholesale, and improving the users' perception of the service. The aim of the paper is to define an econometric model that allows water utilities to determine the optimal budget to be used to finance the maintenance work required to reduce water losses. The model, which uses a Cobb-Douglas production function with increasing returns to scale, identifies the maximum level of profit that the manager can obtain by investing the optimal amount. The higher profits obtained can be used to self-finance new maintenance. A key parameter is the coefficient of return-on-investment α, which is a measure of the degree of user satisfaction with the service offered. The water tariff is dependent on financial (capital and operating), environmental and resource costs. The model is applied to a water utility in the Campania region (Italy).

Keywords: Water service management · Water losses · Maintenance investment · Econometric model · Financial sustainability · Cobb-Douglas function

1 Introduction

Water is the natural element that makes human development possible. The water resource is the main constituent of both the planet and our organism, both of which are composed of approximately 70% water. Of the water on Earth, about 97.5% is found in the oceans and seas, 2% comes from glaciers and polar ice caps, and only 0.5% is available to humans for sustenance. But the percentage of freshwater that is drinkable and not contaminated is even lower and is unevenly distributed over the surface of the planet. Although water is a scarce resource, it is thanks to the water that human beings have achieved the conditions necessary for development. Worldwide, 70% of the water available to man is used for food and in the primary sector, 22% to produce consumer goods and 8% for domestic

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use [1]. The exploitation of the resource is rapidly leading to the irreversible degradation of aquifers. Today, more than 4 billion people live in conditions of water scarcity for at least one month a year and around 500 million people live in places where annual water consumption is double the amount that can be replenished by rainfall [2]. In large parts of the world, water infrastructures are unable to meet the growing need for water. The remarkably low price of water, often below the cost of production, is encouraging the wasteful use of the resource and dampening the inflow of financial capital needed to maintain existing facilities and build new infrastructure [3]. In addition to direct consumption of the resource for domestic and industrial purposes, recent climate change, periods of drought, environmental pollution and hydraulic load losses along distribution networks are contributing strongly to the reduction of drinking water availability. In particular, the issue of water losses is receiving increasing interest from the scientific community [4]. Water losses represent one of the main obstacles to achieving quantitative standards of access and availability of the resource. In any country and network, water loss is a phenomenon that can hardly be eliminated in its entirety. This is because its causes can be multiple (age of plants, pipeline failures, unauthorised withdrawals, measurement errors) and not always easy to predict [5]. In this sense, it is estimated that in Europe, leakages in water networks, leakages from taps and the lack of water-saving facilities are among the main causes of dispersion of about 20–40% of available water resources. The overall percentage of water losses is unevenly distributed across the European Union. In fact, a 2015 CENSIS study reveals that in Germany, network losses amounted to 6.5%, in the UK to 15.5%, in France to 20.9%, and in Italy, they exceeded 50% [6].

The problem of water losses is particularly felt in Italy. Therefore, the aim of this work is to propose an operational tool to support Italian Integrated Water Services operators in defining the budget for investments to limit water losses. Specifically, an econometric model is proposed, whose objective is to establish the optimal annual budget that the individual water service manager should invest in maintenance interventions aimed at reducing water losses of the supply and distribution networks. This budget allows the operator to maximise the operating profit, i.e., to achieve an optimal balance between annual turnover and production costs. The higher profits obtained, some of which are usually set aside in the form of reserves for subsequent years, could be used to finance new maintenance work. The operator can thus resort to self-financing and guarantee the financial sustainability of future investments. Such investments not only lead to an increase in total production costs, but also to an increase in turnover. This is because, as required by the relevant national and EU regulatory framework, water tariffs are defined in such a way as to comprehensively cover all cost components (operating costs, capital costs, environmental costs, and resource costs). As a result, as total production costs increase, the average tariff increases accordingly. In the model, the effects on the user of the service generated by investments aimed at reducing water losses are also considered. These investments contribute to the reduction of environmental and resource costs, which in budgetary terms translate into higher revenues for the operator. This is because increased sensitivity to the ecosystem and improved service can generate increased demand. Some of the users who are dissatisfied with the management of the water resource may change their perception of the managing company. This can be translated into a reduction in the risk of insolvency for the operator and a consequent increase in turnover [7–9].

The document is structured as follows: Sect. 2 defines the main managerial and financial characteristics of the Italian water services to be considered in the model characterization phase; Sect. 3 describes the econometric model; in Sect. 4 the model is applied to an Integrated Water Service manager in the Campania region (Italy) and the main results are presented; in Sect. 5 the results obtained are commented on and interpreted from an economic-financial point of view; Sect. 6 contains the concluding remarks.

2 Overview of the Italian Water Service Management

As mentioned, the Italian situation regarding water losses is particularly serious. In 2018, high losses were recorded along the water networks of provincial capitals: about 44 cubic metres per day per kilometre of the network. In these municipalities, 37.3% of the volume of water injected into the networks did not reach users due to leakage (39% in 2016). With respect to supply interruptions, worrying levels of dissatisfaction on the part of households were recorded in Calabria (36.8%), Sicily (32.4%) and Sardinia (25.6%). In one out of three Italian municipalities, overall losses of more than 45% were recorded. On the contrary, only in one municipality out of five total water losses were below 25% [10]. The need for infrastructure investments in the water supply sector is strongly felt in Italy. The current infrastructural heritage, developed in parallel with the urban and industrial development of the 20th century, is very diverse and has a different residual useful life. For this reason, the investments to be made concern both the construction of new infrastructures and the continuous and constant maintenance of existing ones. To reach acceptable European standards, investments of at least 80 euros per inhabitant would be necessary [11].

In Italy, the financing methods for the construction and maintenance of the infrastructure of the Integrated Water Service are mainly linked to revenues from tariffs and public funds. The latter, which come from European, national, and regional funding as well as from loans granted to local authorities, should represent a decreasing item within the budgets for infrastructure investments since they should be reflected in the tariff according to the principle of full cost recovery. However, flows derived from user payments are still far from adequate thresholds to meet today's needs. Indeed, Italian water tariffs are currently among the lowest in Europe, averaging €1.87 per cubic metre (far from France's €3.67 and Germany's €4.98). On the one hand, low water tariffs encourage wastage of the resource (average annual consumption of about 160 cubic metres of drinking water per inhabitant is estimated), while on the other hand, they limit the scope for investments not financed by the public funds. As a result, the level of investment in water infrastructure is also among the lowest in Europe (e.g., only around 30% of that in the UK). The high levels of losses in Italian distribution networks are therefore mainly due to the reduced availability of financial capital to invest in the maintenance/replacement of existing infrastructure [12].

In Italy, the low flow of investments to improve the efficiency of water networks is partly due to the complex regulatory and legislative framework that characterises the

Integrated Water Service and the model for determining water tariffs. Until 2012, the Ministry of the Environment and Protection of Land and Sea (Ministero dell'Ambiente e della Tutela del Territorio e del Mare - MATTM) defined the cost components for determining the tariff for water services for the various sectors of water use (aqueduct, sewerage, and purification). Today, however, it is an independent administrative authority - the Regulatory Authority for Energy, Networks, and the Environment (Autorità di Regolazione per Energia Reti e Ambiente - ARERA) - which exercises regulatory powers over the Integrated Water Service determines the national method of calculating tariffs and approves them on the proposal of the Ambit Management Body (dell'Ente di Gestione d'Ambito - EGA). The latter is a local body, with a legal personality, which organises, entrusts, and controls the work of the individual water service managers within an Optimal Territorial Ambit (Ambito Territoriale Ottimale - ATO), which represents the minimum territorial unit of reference. The tariffs that each management must apply are therefore proposed by the EGAs based on a technical, economic, and financial planning tool, the Area Plan (Piano d'Ambito - PdA), and subsequently approved by ARERA. All the portions of the tariff for the Integrated Water Service are in the nature of a fee. In fact, the tariff regulations contained in the Consolidated Environmental Act (Testo Unico dell'Ambiente, Legislative Decree 152/2006) state that the tariff is determined considering the quality of the water resource and the service provided, the necessary works, the management costs of these works, and a share of the operating costs of the Ambit Authority. This ensures full coverage and recovery of investment and operating costs according to the polluter pays principle. This is in accordance with the Water Framework Directive promulgated by the European Commission (2000/60/EC), which introduces the concept of full cost recovery, according to which the tariffs charged to users must cover operating, capital costs, and environmental costs [13].

In a similar way to the model for defining water tariffs, the service management model should have followed the approach prevailing in Europe. In fact, in the initial intentions, the reform of the Italian regulations in matters of Integrated Water Service should have been inspired by the management models of England and Wales. In this sense, the main objectives that should have been pursued are the concentration of management (in particular, hoping for the presence of a single manager for each ATO) and the start of an entrepreneurial organisation of the sector to make the service financially autonomous as regards investments in infrastructure. However, the current management model that has emerged from the regulations that have followed over the years has taken on a different physiognomy from the English one. Therefore, the Italian model has appeared in the European panorama as a hybrid model. In fact, the legislator, considering the vast administrative, technical, and political apparatus operating in public enterprises, has in fact accepted the compromise of optional privatisation, leaving the possibility of a public presence in management. At present, an industrial type of management can only be found in a few areas of the country (mostly in the centre-north, in Puglia and Basilicata), while in the south and on the islands, it is almost always the municipalities that manage water services on a tight budget [14].

Significant economies of scale and scope emerge only for a few medium and large-scale management (in terms of employees and catchment area), mostly private and multi-service. In contrast to the small operators, these companies are more financially self-sufficient, in some cases managing to finance their investments from tariff revenues. However, even for these companies, there is enormous room for improvement. Hence the need to propose innovative models and instruments that allow operators to increase the financial sustainability of their investments, especially those necessary for the maintenance of existing plants and the construction of new infrastructure [15–19]. A crucial issue is the definition of the optimal budget to be allocated to these investments, considering both the most efficient technical solution in terms of reducing environmental costs and satisfying the service users and the financial impact in terms of company profits. In the present work, the attention is focused on the maintenance interventions of the aqueduct plants necessary to reduce water losses. In this regard, an innovative model is introduced in the next chapter whose objective is to establish the optimal budget that the managing body should allocate to maintenance interventions to maximise profits. In the following sections, the model will be applied retrospectively on the investments made by the managing body in the last ten years to understand how much the adopted strategy differs from the optimal one.

3 Characterization of the Financial Sustainability Model

In microeconomic terms, water utilities operate under a natural monopoly. This is for several reasons. First, the water network for technical reasons can only be unique. Secondly, the production costs incurred by a single company to provide the required volumes of water are lower than if several companies were operating on the market. Finally, being a public economic activity, the natural monopoly reduces the risk of market failure, guaranteeing the uninterrupted supply of the resource to citizens and industries [20]. In a monopoly market, the inverse market demand for the year $t_0 \leq t \leq t_f$ can be represented through the following functional relationship:

$$p_{(t)} = a - b\,q_{(t)} + c\,C_{T\,(t)} \tag{1}$$

where p is the average water tariff (i.e., the average of the different tariffs by user type and consumption bands, including the fixed fee), q is the quantity of water demanded and C_T is the total production costs. The parameters a, b and c are constants. In particular, a identifies the intercept of the price plane with the Cartesian price axis, while b and c represent the slope of this plane with respect to the same axis. A linear relationship is assumed between the variables. Initially, a relationship of inverse proportionality between p and q was assumed, being the quantity demanded not being independent of the price (and vice versa) as in perfect competition. Therefore, in terms of inverse demand, as the quantity demanded decreases, the average water tariff should increase. For this reason, in (1) the parameter a is preceded by a minus sign. The monopoly company can therefore carry out a policy of both price (in compliance with the maximum tariffs defined by ARERA Resolution 665/2017/R/idr of 28 September 2017 [21]) and quantity. The relationship between p and C_T is, instead, of direct proportionality based on the full cost recovery principle. Therefore, as total production costs increase, the average tariff increases. However, in accounting terms, and therefore in the income statements of the managing bodies, the production cost does not include the following two types of cost:

- Environmental costs: negative externalities arising from the damage that water use causes to the environment, ecosystems, and users (reduction in the ecological quality of water ecosystems, salinisation, degradation of productive land, etc.) [22, 23]. To calculate environmental costs, it is also necessary to consider the mere abstraction of water and, especially, water losses that, in addition to reducing the availability of the resource, do not contribute to an increase in productivity.
- Resource costs: costs arising from the use of the water resource for a specific use rather than for alternative uses (opportunity cost of the resource).

On the other hand, production costs include a large part of financial costs, such as operating costs (raw material costs, service costs, personnel costs, ordinary maintenance), depreciation costs (depreciation allowances, extraordinary maintenance), while capital costs (interest to be paid on investments made) are excluded. In order to follow the full cost recovery principle to the letter, environmental and resource costs must also be considered. The investments made by the managing body that contribute to the reduction of these costs are rewarded by the national regulator (ARERA) through the increase of the water tariff [24, 25]. Virtually, the tariff increase is equivalent to a reduction in the quantity demanded. If the positive effects on the price generated by the investments exceed the negative effects generated by the increase in demand, then it is possible to change the sign of the *a* coefficient in (1). The change of sign from negative to positive is also justifiable for a second reason. The increasing sensibility of the managing body for environmental sustainability (manifested, for example, through investments finalized to the reduction of the water losses) is often welcomed by the users, also by those less satisfied with the offered service. In particular, it is among the latter that there is the highest percentage of insolvents, i.e., those who use the service without paying. Investments to reduce environmental and resource costs can lead to dissatisfied users having a favourable perception of management, helping to reduce the risk of insolvency. Again, this translates into higher revenues for the authority, which can be justified by a change in the sign of the *a* coefficient. The payment of interest to the financing bodies can generate a similar effect, contributing to an increase in the positive opinion of management. The same applies to the reduction of operational costs of drawing the resource at the source obtained by containing water losses. All these elements can result in a change of sign of the *a* coefficient, so (1) can be rewritten as follows:

$$p_{(t)} = a + b\, q_{(t)} + c\, C_{T\,(t)} \tag{2}$$

The average tariff p is obtained by dividing the production revenues (R) by the volumes of water supplied to users (q):

$$p_{(t)} = \frac{R_{(t)}}{q_{(t)}}. \tag{3}$$

Parameters a, b and c *can be* estimated using multiple linear regression and considering the time series of p, q, and C_T. As we shall see, when applying the model, the regression confirmed the positivity of parameter a.

Similarly to the assumptions made by the authors in other application areas [26–28], supply is defined by means of the following Cobb-Douglas production function at increasing returns to scale [29]:

$$q_{(t)} = K_{I(t)}^{\alpha} L_{(t)}^{\beta}\, con\, \alpha + \beta = 1.4 > 1, 0 < \alpha < 1 \; e \; 0 < \beta < 1, \tag{4}$$

where $q_{(t)}$ is the quantity offered, $K_{I\,(t)}$ is the stock of investments accumulated over time and aimed at reducing water losses, $L_{(t)}$ is the labour input. The capital at the disposal of the managing body is not considered among the production factors, as these activities do not contribute directly to production (a building owned, for example, does not directly affect the distribution of water to users). In $K_{I(t)}$, on the other hand, are included the installations of the entire aqueduct network, which is assumed to be publicly owned and managed by the water manager. Each investment $I_{(t)}$ made in the time unit t contributes to the increase of the capital stock $K_{I(t).}$ The exponential coefficients α and β represent the rate of change of the (decreasing) marginal return on capital ($K_{I(t)}$) and labour ($L_{(t)}$), respectively. In particular, the parameter α incorporates within it those intangible aspects that can directly affect productivity, such as the level of user satisfaction with the service offered. As regards the hypothesis of increasing returns to scale ($\alpha + \beta = 1.4 > 1$), it is supported by the reference literature on the Integrated Water Service [30, 31]. This is because it has been empirically demonstrated that the productivity of jointly employed production factors increases exponentially as the size of the management increases. In fact, it is much more difficult for management on a tight budget to achieve high output levels than industrial management with a larger catchment area. Following industry surveys, it was considered acceptable to set $\alpha + \beta = 1.4$ following the national trend in the water services market. Exploiting the log-linearity property of the Cobb-Douglas function and solving the following system it is possible to calculate the values of α and β:

$$\begin{cases} \alpha = 1.4 - \beta \\ \beta = \frac{\ln q - \log K_{I(t)}}{\ln L_{(t)} - \log K_{I(t)}} \end{cases}, \tag{5}$$

Total production costs can be defined as follows:

$$C_{T(t)} = C_A + I_t, \tag{6}$$

where I_t is the cost of the investment to reduce water losses in year t and C_A represents the remaining production costs (including personnel costs). The stock of investments accumulated up to year t can be defined as the sum of the investment I_t with the stock of investments accumulated up to year $t - 1$:

$$K_{I(t)} = I_t + K_{I(t-1)}. \tag{7}$$

In turn, $K_{I(t-1)}$ includes the loss of value suffered by the investment stock over time due to technical and functional obsolescence [32, 33]. By virtue of this, we can estimate $K_{I(t\text{-}1)}$ as follows:

$$K_{I(t-1)} = K_{I(t_0)} + \sum\nolimits_{t_1}^{t-1} (I_t - v_i)\, con\, v_i = \frac{(t-1) - t_1}{U} 100 \; e \; t_0 \le t \le t_f, \tag{8}$$

where $K_{I(t_0)}$ is the value of the entire aqueduct network at year t_0 (i.e., at the beginning of the period under analysis), v_i is the age coefficient applied to the network and *U is* its useful life, which usually is set at 40 years. Having defined the main variables, it is possible to write the profit function $\pi_{(t)}$ as follows:

$$\pi_{(t)} = \left\{a + bK^{\alpha}_{I(t)}L^{\beta}_{(t)} + c\left[C_A + \left(K_{I(t)} - K_{t-1}\right)\right]\right\}K^{\alpha}_{I(t)}L^{\beta}_{(t)} - C_A - K_{I(t)} + K_{I(t-1)}. \tag{9}$$

Under monopoly, entrepreneurial profit is maximised when marginal revenues equal marginal costs. Specifically, the first-order condition is met if the derivative of profits with respect to the stock of investment at time t is zero (i.e., $\frac{\partial \pi_t}{S_{I(t)}} = 0$). We take for granted the second-order condition (downward concavity of the total profits function) [34]. We can therefore write:

$$\left(\beta bK^{(\alpha-1)}_{I(t)}L^{\beta}_{(t)} + c\right)K^{\alpha}_{I(t)}L^{\beta}_{(t)} + \left\{a + bK^{\alpha}_{I(t)}L^{\beta}_{(t)} + cC_A + cK_{I(t)} - cK_{t-1}\right\}\beta K^{(\alpha-1)}_{I(t)}L^{\beta}_{(t)} - 1 = 0 \tag{10}$$

from which we obtain the objective function to be maximised:

$$2\beta bL^{\beta}_{(t)}K^{2(\alpha-1)}_{I(t)} + (1+\beta)cL^{\beta}_{(t)}K^{(\alpha)}_{I(t)} + (a + cC_A - cK_{t-1})\beta bL^{\beta}_{(t)}K^{(\alpha-1)}_{I(t)} - 1 = 0. \tag{11}$$

Finally, by posing:

$$\begin{cases} 2\beta bL^{\beta}_{(t)} = A \\ (1+\beta)cL^{\beta}_{(t)} = B \\ (a + cC_A - cK_{t-1})\beta bL^{\beta}_{(t)} = C \end{cases}, \tag{12}$$

we obtain:

$$AK^{2(\alpha-1)}_{I(t)} + BK^{(\alpha)}_{I(t)} + CK^{(\alpha-1)}_{I(t)} - 1 = 0. \tag{13}$$

Equation (13), which is of degree *(α − 1),* can be easily solved using the Excel solver for each $t_0 \leq t \leq t_f$. In solving Eq. (13), since the average tariff increases as the investment increases, the following constraint must be introduced: the tariff *p(t)* cannot exceed a maximum value p_{MAX} set by the standard. Specifically, this threshold was set at 4.80 €/m^3 (national average value of the third-class excess tariff including a representative share of fixed costs [21]). It is thus possible to obtain $K_{I(t)}*$, i.e., the optimal stock of investment that should be accumulated at time *t to* maximise the entrepreneurial profit. The optimal investment at time t can be calculated as follows:

$$I^*_t = K^*_{I(t)} - K_{I(t-1)}. \tag{14}$$

Finally, the maximum achievable profit at time t is obtained from the following equation:

$$\pi_{MAX\,(t)} = \left\{a + bK^{*\alpha}_{I(t)}L^{\beta}_{(t)} + c\left[C_A + \left(K^*_{I(t)} - K_{I(t-1)}\right)\right]\right\}K^{*\alpha}_{I(t)}L^{\beta}_{(t)} - C_A - K^*_{I(t)} + K_{I(t-1)} \tag{15}$$

In the next section, the model is applied to a manager of the Integrated Water Service in the Campania region (Italy) with the aim of estimating the annual investment that would have allowed him in each of the ten years of the reference time horizon (2010–2019) to maximise entrepreneurial profit.

4 Application and Results

The managing body selected for the case study offers a plurality of services. In addition to services related to the management of the public aqueduct (collection, adduction, and distribution of water for domestic, commercial, and industrial use), it also offers non-water services, such as gas distribution, maintenance of public green spaces and, ordinary and extraordinary maintenance of roads. Sewerage and purification services, which are further characteristic activities of the Integrated Water Service, are instead offered in the municipality by two other companies. The aqueduct service covers the entire municipal territory, serving a population of approximately 12,000 inhabitants and 5,500 users. The aim of the company is to manage the aqueduct service as well as the construction of the related plants and their consequent maintenance in the municipality where it is managed. The tariffs for the sewerage and purification services are collected by the manager of the aqueduct service, who then distributes them among the other managers. The financial sustainability model was applied using as variables the financial statement data for the last ten years of management available (financial years 2010 to 2019), i.e., published by the Chamber of Commerce, Industry, Crafts and Agriculture.

Since we are interested in analysing only the profits related to the aqueduct service, the balance sheet items were reclassified by compartments (aqueduct, sewerage, purification, other water activities, miscellaneous activities) according to the scheme proposed by AEEGSI (now ARERA) with Resolution 137/2016/R/com [35]. For example, those revenues attributable to the collection of sewerage and purification service tariffs that have not yet been credited to other managing bodies in the year of reference have been subtracted from the value of production. Similarly, the financial statements were purged of revenues and costs relating to gas distribution activities and the maintenance of roads and public parks. In the case of operational functions and activities shared between several different compartments, the individual revenue or cost item has been broken down through a driver as suggested by the standard. Table 1 shows the balance sheet data of the aqueduct sector and the other economic-management data necessary for the application of the model. For each year t, the average water tariff was obtained from (3), while the investment stock was estimated by applying (7) and (8).

Parameters a, b and c were estimated using multiple linear regression (R multiple 0.876, R^2 0.732, R^2 corrected 0.542, standard error 0.014). The values obtained are $a = 0.9389474385$, $b = 0.0000000271$ and $c = 0.0000002999$. Having calculated the natural logarithms of $q_{(t)}$, $K_{I(t)}$ and $L_{(t)}$, it was possible to estimate the α and β constants (shown in Table 2) of the Cobb-Douglas function for each t from (5).

Using the solver function it is possible to estimate the value of $K_{I(t)}$ that makes the objective function (13) converge to zero for each t. Applying (14) and (15) we obtain the optimal investment $I_{(t)}$ and the maximum feasible tariff π_{MAX} (see Table 3).

The profits obtained can be further increased by subtracting the cost of purchased wholesale water. In fact, in the real scenario, the resource withdrawn at source net of water losses did not meet the demand for any of the years considered. For each t, the quantity demanded q (volumes of water sold to users) is equal to the volumes withdrawn (w_w) minus the water losses (w_l) plus the volumes purchased (w_p). Water losses (w_l) are equal to the difference between the volumes withdrawn (w_w) and the volumes distributed to users (w_d). In ten years, these losses amounted to about 45% of the volumes withdrawn,

Table 1. Data required for the application of the financial sustainability model.

Years	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
q (m^3)	947,154	961,157	878,672	903,895	1,102,665	1,138,847	1,147,958	1,068,113	1,108,036	1,088,074
p (€/m^3)	1.55	1.12	1.10	1.08	1.37	1.41	1.25	1.40	1.31	1.33
R (€)	1,469,821	1,072,524	962,930	975,564	1,506,094	1,609,456	1,438,085	1,494,373	1,452,822	1,442,152
CT (€)	971,947	704,656	773,741	660,010	1,111,738	1,111,738	1,319,984	1,398,322	1,361,337	1,393,245
π (€)	497,874	367,869	189,189	315,554	394,356	497,718	118,101	96,051	91,484	48,907
Ca (€)	919,026	684,115	747,463	628,071	1,014,330	1,018,580	1,259,690	1,313,878	1,269,694	1,340,686
I (€)	52,921	20,540	26,278	31,939	97,408	93,158	60,294	84,444	91,643	52,559
L (cad)	15	15	15	15	13	12	12	12	12	12
K_I (€)	1,052,921	1,072,138	1,096,580	1,126,025	1,220,141	1,307,572	1,359,810	1,434,691	1,514,659	1,553,252

Table 2. Estimation of the α and β constants of the Cobb-Douglas function.

dati	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
α	0.89344	0.89331	0.88350	0.88394	0.90155	0.90239	0.90004	0.88975	0.88876	0.88532
β	0.50656	0.50669	0.51650	0.51606	0.49845	0.49761	0.49996	0.51025	0.51124	0.51468

Table 3. Results of the optimisation problem.

t_i (years)	K_I* (€)	I* (€)	q* (m^3)	C_T* (€)	p* (€/m^3)	R* (€)	π_{MAX} (€)
2010	1,967,844	967,844	1,656,056	1,886,870	1.85	3,056,073	1,169,203
2011	2,818,240	850,396	2,278,980	2,449,434	1.67	3,816,784	1,367,350
2012	3,532,622	2,460,484	2,469,990	3,207,947	1.87	4,616,278	1,408,331
2013	3,547,787	2,451,208	2,492,756	3,079,278	1.85	4,606,106	1,526,828
2014	2,090,327	964,301	1,791,552	1,978,632	1.64	2,946,185	967,553
2015	2,080,817	860,676	1,731,967	1,879,256	1.66	2,874,125	994,870
2016	2,547,074	1,239,502	2,019,502	2,499,193	1.63	3,291,694	792,501
2017	2,986,017	1,626,208	2,050,474	2,940,085	1.89	3,871,330	931,245
2018	3,266,615	1,831,924	2,193,854	3,101,619	1.86	4,085,923	984,304
2019	3,519,823	2,005,164	2,244,883	3,345,850	1.94	4,360,190	1,014,340
average	2,835,717	1,525,771	2,093,001	2,636,816	2	3,752,469	1,115,653

in line with the average regional figure for 2015 (middle year of the time horizon) [36]. Similar percentages can be found for other Campania utilities of a similar size to the one under study.

It is found that about 15% of the water sold to users was purchased by the manager at wholesale at a unit price (p_p) of €/m^3 0.2697. The cost of the wholesale purchased water (Cw) for each t is equal to the product of p_p and w_p. Table 4 shows the volumetric data and the cost of wholesale purchased water for the real scenario. For this scenario, the available data show that with an average annual investment of €61,118, water losses are reduced by an average of 1.24% per year. Proportionally, the optimal average annual investment of €1,617,263 (see Table 3) should allow the operator to reduce leakage by an average of 32.78% per year.

Furthermore, if we assume a direct proportionality relationship between volumes demanded by users (q) and volumes withdrawn at source (w_w), then known $q*$ it is easy to obtain the withdrawn volumes for the optimal scenario (w_{w*}). From these it is possible to estimate all other volumes for the optimal scenario (see Table 5).

Table 4. Volumetric data and cost of water purchased in bulk: real scenario.

Years	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
w_w (€/m^3)	1,373,373	1,393,678	1,274,074	1,310,648	1,598,864	1,651,328	1,664,539	1,548,764	1,606,651	1,577,708
w_d (€/m^3)	805,081	816,983	746,871	768,311	937,265	968,020	975,764	907,896	941,830	924,863
w_l (€/m^3)	568,292	576,694	527,203	542,337	661,599	683,308	688,775	640,868	664,821	652,845
w_p (€/m^3)	142,073	144,174	131,801	135,584	165,400	170,827	172,194	160,217	166,205	163,211
q (€/m^3)	947,154	961,157	878,672	903,895	1,102,665	1,138,847	1,147,958	1,068,113	1,108,036	1,088,074
Cw (€)	38,317	38,884	35,547	36,567	44,608	46,072	46,441	43,211	44,826	44,018

Table 5. Volumetric data and cost of water purchased in bulk: optimal scenario.

Years	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
w_{w^*} (€/m^3)	2,401,281	3,304,521	3,581,485	3,614,497	2,597,751	2,511,353	2,928,277	2,973,187	3,181,089	3,255,081
w_d * (€/m^3)	1,733,387	2,385,400	2,585,329	2,609,159	1,875,211	1,812,844	2,113,805	2,146,223	2,296,299	2,349,711
w_l * (€/m^3)	667,894	919,121	996,156	1,005,338	722,540	698,509	814,473	826,964	884,790	905,370
w_p * (€/m^3)	−77,332	1–06,420	−115,339	−116,402	−83,659	−80,876	−94,303	−95,749	−102,445	−104,828
q* (€/m^3)	1,656,056	2,278,980	2,469,990	2,492,756	1,791,552	1,731,967	2,019,502	2,050,474	2,193,854	2,244,883
Cw* (€)	−20,856	−28,701	−31,107	−31,394	−22,563	−21,812	−25,434	−25,824	−27,629	−28,272

For each year, the optimal investment generates an increase in demand, as users have a better perception of the service. Together with demand, the volumes of water extracted at the source increase proportionally. Although water losses also increase, they increase less than proportionally to demand, due to improvements in the water systems. As a result, the volumes supplied to users exceed demand. Rather than buying wholesale water, the operator could sell excess water to further increase revenues or, alternatively, reduce the water supply by reducing the cost of extracting the resource. If we add to C_A (production cost net of investment I*) the cost Cw* (which is negative), we get a new adjusted production cost (C_{R*}) which if inserted in (15) returns an even higher maximum profit (see Table 6).

Table 6. Adjusted results of the optimization problem (without wholesale purchase).

t_i (years)	K_I* (€)	I* (€)	q^*_{ADJ} (m^3)	C_T* $_{ADJ}$ (€)	p* $_{ADJ}$ (€/m^3)	R* $_{ADJ}$ (€)	$\pi_{MAX, ADJ}$ (€)
2010	1,967,844	967,844	1,656,056	1,866,014	1.84	3,045,716	1,179,703
2011	2,818,240	850,396	2,278,980	2,420,733	1.67	3,797,170	1,376,438
2012	3,532,622	2,460,484	2,469,990	3,176,840	1.86	4,593,238	1,416,398
2013	3,547,787	2,451,208	2,492,756	3,047,885	1.84	4,582,640	1,534,756
2014	2,090,327	964,301	1,791,552	1,956,069	1.64	2,934,064	977,995
2015	2,080,817	860,676	1,731,967	1,857,443	1.65	2,862,797	1,005,354
2016	2,547,074	1,239,502	2,019,502	2,473,759	1.62	3,276,292	802,533
2017	2,986,017	1,626,208	2,050,474	2,914,262	1.88	3,855,452	941,190
2018	3,266,615	1,831,924	2,193,854	3,073,989	1.85	4,067,747	993,758
2019	3,519,823	2,005,164	2,244,883	3,317,578	1.93	4,341,159	1,023,581
average	2,835,717	1,525,771	2,093,002	2,610,457	2	3,735,628	1,125,171

The results obtained will be commented on in the next section.

5 Discussion

To understand the advantages obtained by increasing the investments aimed at reducing water losses by the right amount, it is necessary to compare the real investment and profit levels with the optimal ones. Figure 1 shows the evolution of I and I* over time.

In contrast to the investments actually made by the manager, which follow an almost linear trend and remain more or less constant over time, the optimal investments, in addition to being significantly higher, show a cyclical pattern. Figure 2 shows the time trend of π and π_{MAX}.

The maximum profits are parallel to those actually pursued only in some years, namely between 2012 and 2013 and then between 2014 and 2016. For the other years π_{MAX} and π have a mirror-image trend.

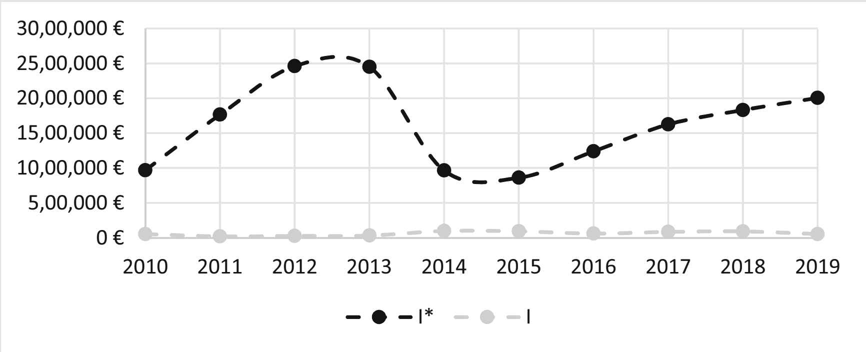

Fig. 1. Evolution of I and I* over time.

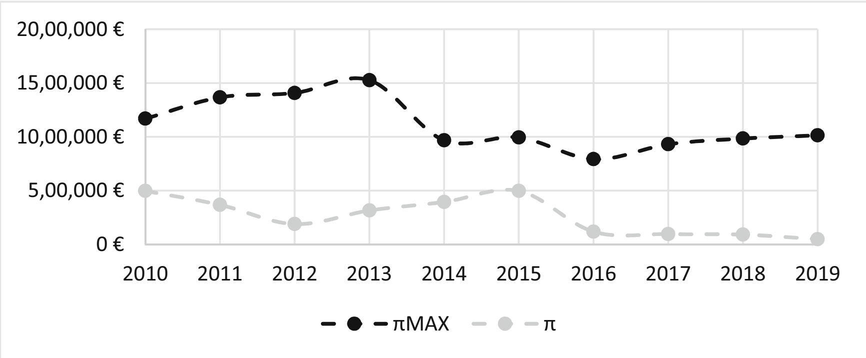

Fig. 2. Evolution of π e π_{MAX} over the time.

6 Conclusions

In Italy, Europe's leading country in terms of water withdrawals for drinking, there is a wide gap between the water resources fed into the distribution networks and those supplied to users. This is especially true in the South, where water losses are around 46% [37]. In addition to the damage inflicted on the environment, water losses are also a problem for water utilities. Although the complete elimination of leakages is impossible, the objective of any efficient operator is to limit losses of the distribution network. This has several benefits, including reducing production and distribution costs, limiting the volume of water purchased in bulk and improving the perception of the service by users. On the latter point, the impact that the losses reduction has on the users can affect water tariffs. This effect is crucial for those services under management concession that use tariff leverage, by foregoing part of the profit, to self-finance investments aimed at reducing water losses [31]. It is, therefore, necessary to assess the limits and benefits of such investments using appropriate models.

The aim of this work is to define an econometric model that allows water utilities to establish the optimal budget to be used to finance the maintenance work required to reduce water losses. The model identifies the maximum level of profit that the operator can pursue by investing the right amount of money. A key parameter is a coefficient that measures the rate of change of the investment return (α), which incorporates those intangible aspects that affect productivity, such as user perception of the service. A similar function is performed by the (a) coefficient in the price equation. According to this equation, the average tariff depends on financial costs (capital and operating costs), environmental costs and resource costs. In addition, it is possible to include in the model the profit effects generated by the decrease in wholesale water purchase costs following maintenance interventions.

References

1. Sparano, E.: Obiettivo acqua. Educazione, etica e valori alla base dello sviluppo sostenibile. Culture e Studi del Sociale **5**(1), 101–118 (2020)
2. RINNOVABILI.IT Homepage. https://www.rinnovabili.it/ambiente/scarsita-acqua-problema-grave-333/. Accessed 03 July 2021
3. Piotti, A., Ronco, G.: Alcune considerazioni sulla distribuzione e sul consumo dell'acqua potabile. L'ACQUA - Rivista bimestrale dell'Associazione Idrotecnica Italiana **1** (2007)
4. Dono, G., Marongiu, S., Severini, S., Sistu, G., Strazzera, E.: Studio sulla gestione sostenibile delle risorse idriche: analisi dei modelli di consumo per usi irrigui e civili. ENEA, Collana Desertificazione – Progetto RIADE (2008)
5. Vitiello, M.: Il sistema idrico italiano: un confronto con i principali Paesi europei. Tesi di Laurea in Economia e gestione dei servizi di pubblica utilità, Luiss Guido Carli, relatore Simona D'Amico, p. 49 (2020)
6. Censis: Quarantottesimo rapporto sulla situazione sociale del Paese. Franco Angeli (2014)
7. González-Méndez, M., Olaya, C., Fasolino, I., Grimaldi, M., Obregón, N.: Agent-based modeling for urban development planning based on human needs. Conceptual Basis Model Formulation. Land Use Policy **101**, 105110 (2021). https://doi.org/10.1016/j.landusepol.2020.105110
8. Grimaldi, M., Sebillo, M., Vitiello, G., Pellecchia, V.: Planning and managing the integrated water system: a spatial decision support system to analyze the infrastructure performances. Sustainability **12**(16), 6432 (2020). https://doi.org/10.3390/su12166432
9. Sebillo, M., Vitiello, G., Grimaldi, M., De Piano, A.: A citizen-centric approach for the improvement of territorial services management. ISPRS Int. J. Geo Inf. **9**(4), 223 (2020). https://doi.org/10.3390/ijgi9040223
10. ISTAT: Le statistiche dell'Istat sull'acqua - anni 2018–2019 (2020)
11. Macchiaroli, M., Pellecchia, V., D'Alpaos, C.: Urban water management in Italy: an innovative model for the selection of water service infrastructures. WSEAS Trans. Environ. Dev. **15**, 463–477 (2019)
12. LA REPUBBLICA Homepage. https://www.repubblica.it/economia/2019/11/09/news/acqua_rubinetto_ambrosetti-240292743/. Accessed 14 August 2020
13. Cauduro, A.: Il ruolo pubblico nella determinazione della tariffa del servizio idrico integrato. Politica del diritto **2**, 229–258 (2020)
14. Muraro G.: La gestione del servizio idrico integrato in Italia, tra vincoli europei e scelte nazionali. Mercato Concorrenza Regole **2** (2003)
15. Nesticò, A., Somma, P.: Comparative analysis of multi-criteria methods for the enhancement of historical buildings. Sustainability **11**(17), 4526 (2019). https://doi.org/10.3390/su11174526

16. Nesticò, A., Maselli, G.: Declining discount rate estimate in the long-term economic evaluation of environmental projects. J. Environ. Acc. Manag. **8**(1), 93-110 (2020). https://doi.org/10.5890/JEAM.2020.03.007
17. De Mare, G., Granata, M.F., Forte, F.: Investing in Sports Facilities: The Italian Situation Toward an Olympic Perspective. In: Gervasi, O., et al. (eds.) ICCSA 2015. LNCS, vol. 9157, pp. 77–87. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-21470-2_6
18. Benintendi, R., De Mare, G.: Upgrade the ALARP model as a holistic approach to project risk and decision management. Hydrocarb. Process. **2017**(9), 75–82 (2017)
19. De Mare, G., Di Piazza, F.: The role of public-private partnerships in school building projects. In: Gervasi, O., et al. (eds.) ICCSA 2015. LNCS, vol. 9156, pp. 624–634. Springer, Cham (2015). https://doi.org/10.1007/978-3-319-21407-8_44
20. Castoldi, F.: Il servizio idrico nazionale: problematiche attuali e prospettive di riforma. PhD Thesis, University of Milan - Bicocca, Milan, Italy (2010)
21. Autorità di Regolazione per Energia Reti e Ambiente: Testo Integrato Corrispettivi Servizi Idrici (TICSI), deliberazione 665/2017/R/idr del 28 settembre 2017, Allegato A (2017). https://www.arera.it/it/docs/17/665-17.htm
22. Salvo, F., Morano, P., De Ruggiero, M., Tajani, F.: Environmental health valuation through real estate prices. In: Bevilacqua, C., Calabrò, F., Della Spina, L. (eds.) NMP 2020. SIST, vol. 178, pp. 768–778. Springer, Cham (2021). https://doi.org/10.1007/978-3-030-48279-4_72
23. Salvo, F., Zupi, M., De Ruggiero, M.: Land consumption and urban regeneration. evaluation principles and choice criteria. In: Calabrò, F., Della Spina, L., Bevilacqua, C. (eds.) ISHT 2018. SIST, vol. 100, pp. 582–589. Springer, Cham (2019). https://doi.org/10.1007/978-3-319-92099-3_65
24. Boggia, A, Rocchi, L.: Applicazione del "costo pieno" dell'acqua (Direttiva 2000/60/CE) in un'azienda dell'alto Tevere umbro. In: Casini, L., Gallerani, V. (eds.) Acqua, agricoltura e ambiente nei nuovi scenari di politica comunitaria, Franco Angeli, Milan, Italy (2008)
25. Sbandati, A.: Servizi ecosistemici, servizio idrico integrato e componenti tariffarie: l'opportunità dei Payments for Ecosystem Services (2020). http://hdl.handle.net/20.500.12010/17532. Accessed 27 Mar 2021
26. Dolores, L., Macchiaroli, M., De Mare, G.: A dynamic model for the financial sustainability of the restoration sponsorship. Sustainability **12**(4), 1694 (2020). https://doi.org/10.3390/su12041694
27. Dolores, L., Macchiaroli, M., De Mare, G.: Sponsorship's financial sustainability for cultural conservation and enhancement strategies: an innovative model for sponsees and sponsors. Sustainability **13**(16), 9070 (2021). https://doi.org/10.3390/su13169070
28. Dolores, L., Macchiaroli, M., De Mare, G.: A model for defining sponsorship fees in public-private bargaining for the rehabilitation of historical-architectural heritage. In: Calabrò, F., Della Spina, L., Bevilacqua, C. (eds.) ISHT 2018. SIST, vol. 101, pp. 484–492. Springer, Cham (2019). https://doi.org/10.1007/978-3-319-92102-0_51
29. Cobb, C.W., Douglas, P.H.: A theory of production. Am. Econ. Rev. **18**, 139–165 (1928). https://www.jstor.org/stable/1811556
30. Bianco, G., Cecati, P.: Costi di produzione ed erogazione di acqua potabile. Una proposta di analisi dell'efficienza. Economia pubblica (1–2), 79–116 (2008)
31. Bazzurro, N., Mazzola, M.: Aspetti economici nelle strategie di gestione delle perdite idriche. In: Brunone, B., Ferrante, M., Meniconi, S., (eds.) Ricerca e controllo delle perdite nelle reti di condotte, pp. 3–44. Città Studi Edizioni, Turin, Italy (2008)
32. Nesticò, A., De Mare, G., Frusciante, B., Dolores, L.: Construction costs estimate for civil works. a model for the analysis during the preliminary stage of the project. In: Gervasi, O., et al. (eds.) ICCSA 2017. LNCS, vol. 10408, pp. 89–105. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-62404-4_7

33. De Mare, G., Nesticò, A., Macchiaroli, M., Dolores, L.: Market prices and institutional values. In: Gervasi, O., et al. (eds.) ICCSA 2017. LNCS, vol. 10409, pp. 430–440. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-62407-5_30
34. Varian, H.R.: Microeconomia. 7th edn. Libreria Editrice Cafoscarina, Venezia, Italy (2011). ISBN 9788875433079
35. Autorità per l'Energia Elettrica, il Gas e il Sistema Idrico: Testo integrato delle disposizioni dell'AEEGSI in merito agli obblighi di separazione Contabile (TIUC), deliberazione 2016137/2016/R/com del 24 marzo 2016, Allegato A (2016). https://www.arera.it/it/docs/16/137-16.htm
36. Istituto Nazionale di Statistica (ISTAT): le statistiche dell'istat sull'acqua - anni 2018–2020. https://www.istat.it/it/archivio/255596#:~:text=Nel%202018%2C%20non%20sono%20collegati,abbastanza%20soddisfatta%20del%20servizio%20idrico. Accessed 07 Mar 2021
37. Legambiente: Acqua e ambiente: criticità e opportunità per migliorarne la gestione in Italia. https://www.legambiente.it/wp-content/uploads/2021/03/Acque-in-rete_dossier-2021.pdf. Accessed 07 Mar 2021