Documents de travail

«The hidden costs of drinking water rationing in water-stressed Mediterranean countries: Evidence from Algeria»

Auteurs

Ali ZEGGAGH, Serge GARCIA

Document de Travail n° 2025 – 19

Avril 2025

Bureau d'Économie Théorique et Appliquée BETA

https://www.beta-economics.fr/

Contact :
jaoulgrammare@beta-cnrs.unistra.fr

The hidden costs of drinking water rationing in water-stressed Mediterranean countries: Evidence from Algeria

Ali ZEGGAGH and Serge GARCIA

Ali ZEGGAGH, LED Laboratory, Facutly of Economics, University of Bejaia, 06000 Bejaia, Algeria. Email: ali.zeggagh@univ-bejaia.dz

Serge GARCIA, Université de Lorraine, Université de Strasbourg, AgroParisTech, CNRS, INRAE, BETA, 54000 Nancy, France. Email: serge.garcia@inrae.fr

ABSTRACT

Water scarcity is a major challenge in many Mediterranean countries, where intermittent water supply and inefficient distribution lead to significant economic and social costs. This paper examines the cost structure of drinking water utilities in Algeria, focusing on the impact of water rationing, network inefficiencies and production constraints. Using a translog cost function estimated with a Cluster-Robust Correlated Random Effects Instrumental Variable (CRE-IV) approach, we analyse the determinants of variable costs and assess network economies such as economies of density and scale, as well as trade-offs in water supply management.

Our results indicate the presence of economies of scale in both water production and distribution, with cost elasticities of 0.7415 for production capacity and 0.7904 for distributed volume, suggesting that expanding service coverage can reduce average costs. However, we find strong cost complementarities between water losses and distributed volume, suggesting that utilities often prioritise increasing supply over network maintenance. Furthermore, the interaction between (possibly reduced) service hours and production capacity shows a significant positive effect on marginal costs due to the water availability constraint, highlighting the economic burden of continuous water supply in a context of resource scarcity.

By estimating the shadow price of water in situ, we quantify the opportunity cost of water abstraction, and find a value of 18.59 DZD/m^3, compared to the estimated marginal cost of 5.77 DZD/m^3. This reflects the problem of water scarcity and the inefficiency of current supply strategies. Our findings underscore the need for better resource allocation policies that emphasise network rehabilitation, demand-side management and cost-reflective pricing mechanisms, hence providing important insights for policy makers seeking to improve the efficiency and sustainability of water supply systems in water-stressed regions.

Keywords: Drinking water distribution, water supply interruptions, water scarcity, water losses, cost function, shadow price of water

JEL Classification: C23, C26, D24, L95, Q25

Acknowledgements

We would like to thank the Algerian Water Company and its various agencies for their invaluable support in providing data on drinking water services. We thank Céline Nauges for very helpful conversations and advice that helped to improve the paper.

1. Introduction

Water scarcity and the efficient distribution of drinking water remain two of the most critical challenges in many Mediterranean countries. The Intergovernmental Panel on Climate Change (IPCC) identifies the Mediterranean as one of the most vulnerable regions to climate change, with projections of reduced water availability due to declining precipitation and increasing evaporation rates (Ali et al., 2022). Algeria, in particular, is facing increasing difficulties due to recurrent droughts, rising temperatures and ageing water infrastructure, leading to significant water losses and increasing water rationing. In Algeria, reservoirs and dams, vital sources of drinking water, are often depleted due to prolonged droughts and extreme temperatures exceeding 40°C (World Bank, 2021). As a result, access to continuous drinking water is often disrupted, a challenge that is not unique to Algeria but also affects Tunisia, Morocco and southern parts of Europe such as Catalonia and Sicily (MedECC, 2020).

Despite these challenges, Algeria has made significant progress in expanding access to drinking water, with 98% of households connected to the water supply network (Ministry of Water Resources, 2017). However, water distribution networks suffer from significant inefficiencies, in particular high levels of water loss due to leakage. In some regions, losses of up to 40% of the water supplied have been reported before it reaches consumers (Bouferrouk et al., 2018). The situation is particularly dire in urban centres, including the capital Algiers, where visible leaks on pavements highlight the severity of the problem. These inefficiencies not only waste a scarce resource, but also exacerbate service interruptions and increase operating costs. Addressing these issues requires investment in infrastructure modernisation, leakage reduction and improved water management strategies.

The economic literature on water supply costs is extensive, but studies focusing on Algeria remain scarce due to data limitations. Existing studies mainly rely on aggregate data, with a few notable exceptions. Zeggagh (2012) uses panel data techniques to analyse water pricing, while Zeggagh (2020) integrates supply and demand side factors to estimate optimal prices for domestic water services. More recently, Zeggagh and Mazouz (2024) apply a translog cost function to assess the efficiency of Algerian water services, highlighting the impact of distribution frequency on costs and economies of scale.

A key issue in the management of water services is the combined effect of two major inefficiencies: water losses in the network and service interruptions due to water rationing. While water scarcity remains the primary driver of rationing, high levels of leakage further reduce effective supply and exacerbate periods of distribution restrictions. Utilities must balance investments in infrastructure maintenance (e.g., repairing leaks, which increases labour and capital costs) with the need to maintain water distribution, which often requires higher energy inputs to compensate for lost volumes (Garcia and Thomas, 2001) and ensure service continuity (Khelladi, 2006). Understanding these interactions is essential for optimising resource allocation and improving the reliability of water services.

Recent studies have increasingly focused on the economic costs associated with water use, especially in the context of water scarcity and efficiency improvements. Molinos-Senante et al. (2016) introduce the concept of the sustainable economic level of leakage, and use a directional distance function to estimate the shadow price of water leakage in Chile. Their results show that leakage costs account for about 32% of the water price, highlighting the importance of addressing water losses to improve environmental and economic outcomes. Similarly, Brea-Solis et al. (2017) highlight the impact of droughts in England and Wales, challenging the idea of abundant water resources. After estimating an input-distance function, they estimate a shadow price, taking into account the trade-off between water losses and environmental investments. In a later study, Molinos-Senante et al. (2019) further investigate leakage costs for Chilean water companies, estimating that the cost of losing one cubic metre of water is €0.44/m^3, and argue for stronger regulatory incentives to reduce leakage. Finally, María Molinos-Senante et al. (2022) use multi-directional data envelopment analysis to assess the efficiency of Chilean water companies in reducing water leakage and unplanned service interruptions. They estimate significant potential water and time savings, demonstrating the financial and operational benefits of improving water distribution efficiency. Together, these studies highlight the critical role of shadow pricing and efficiency metrics in water resource management and policy making.

This study estimates the cost of providing drinking water in Algeria, taking into account both production and distribution costs, as well as two performance indicators: the water loss rate (the difference between the volume produced and the volume distributed divided by the volume produced) and the total hours of supply per week, which reflects the frequency of service. This approach provides a comprehensive assessment of technological efficiency and input cost dynamics. In addition, we estimate the shadow price of water to capture its scarcity and opportunity costs, providing important insights for improving water management strategies. By quantifying the economic impact of water losses and intermittent supply, we provide guidance for utilities to adopt more sustainable and cost-effective policies.

To analyse the cost structure of Algerian water utilities, we use a translog cost function, a flexible approach that captures non-linear interactions between inputs, outputs and other technological factors, while allowing for the estimation of economies of scale and technological inefficiencies. Given the panel nature of our data, it is crucial to control for unobserved individual heterogeneity and potential endogeneity issues. To address this, we use the correlated random effects (CRE) approach, building on Mundlak (1978) and Krishnakumar (2006). This method extends the standard random effects model by incorporating the means of time-varying explanatory variables, allowing us to retain the benefits of the fixed effects estimator while identifying coefficients for time-invariant variables (Wooldridge, 2010). In addition, to mitigate biases arising from simultaneity between output choices and cost structures, we implement an instrumental variable (IV) method based on a control function approach. This methodological framework, combined with a careful adjustment for clustering in the standard error corrections, ensures robust and efficient estimates.

This paper uses the translog cost function, a structural econometric model that exploits the fundamental duality between cost and production functions. This duality allows for the inference of key technological characteristics, such as input substitution patterns and economies of scale, without requiring explicit knowledge of the underlying production process. Furthermore, the estimation of the cost function helps to analyse technological inefficiencies and the drivers of production costs, thus providing valuable insights into the cost dynamics of the Algerian water sector.

The translog specification continues to be widely used in applied economics to examine the interplay between cost, quality and output in different sectors. For example, Xiao et al. (2024) use a similar approach to analyse the dynamics of cost, quality and output in England's residential care sector for people with learning disabilities. Similarly, Filippini et al. (2022) assess efficiency and productivity in Swiss nursing homes using panel data along the translog cost frontier. In the water sector, Molinos-Senante et al. (2019) and Maziotis and Molinos-Senante (2022) apply translog cost and distance functions to estimate economies of scale, scope and total factor productivity. Similarly, Mardones and Orellana (2023) use this functional form to model an input demand system, allowing for the estimation of substitution elasticities and the elasticity of industrial water demand in Chile. Taken together, these studies highlight the continuing relevance of the translog approach to empirical cost analysis in a variety of industries, and reinforce its applicability and value in the water sector.

The study is structured as follows: Section 2 gives an overview of the water sector in Algeria. Section 3 presents the economic model, which takes into account the specifics of the production technology in the drinking water supply sector, the performance indicators and the constraints associated with water scarcity. Section 4 outlines the econometric methodology used to estimate the variable cost function. Section 5 presents the data set and interprets the estimation results. Finally, Section 6 discusses the management and policy implications and concludes the study.

2. The water sector in Algeria

Algeria's water sector is characterised by significant investment in hydraulic infrastructure, including dams, wastewater treatment plants, demineralisation plants, desalination plants and interregional water transfers. National water policy has focused primarily on developing and securing additional raw water supplies. The Algerian authorities have recognised not only the growing challenges of water scarcity, but also the need for integrated water resource management (IWRM). IWRM is a strategic approach that coordinates water resources at the basin level to meet growing demand efficiently. Significant efforts have been made to increase water availability through various channels.

Algeria currently operates 80 dams, with more under construction. In addition, 16 seawater desalination plants have been built, with more under development in most of the coastal wilayas, to ensure the supply of drinking water, particularly during peak summer periods. Wastewater treatment plants have also been established, which treat an average of 400 million cubic metres per year. This capacity could potentially increase to 600 million cubic metres upon completion of the programme set out by the Ministry of Water Resources. Treated wastewater is now considered the fourth water resource in Algeria, after surface water, groundwater and desalination. This approach aims to allocate more freshwater resources to agriculture and the overall sustainability of water supply. In addition, desalination plants in the southern wilayas, such as Ouargla, play a crucial role, with nine stations in Ouargla alone.

Despite these extensive efforts, water scarcity remains a critical issue in Algeria, as two-thirds of the country is arid or semi-arid. Effective water management is essential and requires continued investment in financial and technological resources to support economic growth and ensure a sustainable water supply. While hydraulic infrastructure helps regulate water availability, the fight against water scarcity is far from over. Mobilising water resources by all available means remains a key policy, but is constrained by regional resource availability and high investment costs. As a result, demand management is emerging as a key strategy to address water scarcity, especially in the short term.

As demand continues to outstrip supply, it is essential to both mobilise resources and implement efficient water management tools. Algeria faces the challenge of raising public awareness of the scarcity and value of water. Promoting water conservation, reducing losses through optimised management of public water services, and implementing effective awareness campaigns are both socially beneficial and economically viable. A key strategy is water pricing reform, which can act as an incentive to conserve the resource. A structured tariff system that reflects usage levels and consumption patterns can encourage responsible use while maintaining the sustainability of the resource. All water users, including households, industry and agriculture, are charged under this system, which reinforces awareness of water scarcity through economic mechanisms.

According to the UN World Water Development Report (2014), agriculture accounts for 70% of Algeria's water consumption, followed by industry at around 20% and domestic use at just 10% of total annual withdrawals. On average, Algerians consume 470 cubic metres of water per year. However, this does not mean that access to drinking water is limited, as 98% of households are connected to the water supply network and 92% to the sewerage system.[1] These figures underline the state's commitment to ensuring access to domestic water as a fundamental responsibility.

Since the early 2000s, the government has stepped up its efforts through the National Water Plan, which prioritises investment in water resource mobilisation. Despite these measures, drinking water

[1] Ministry of Water Resources (2017).

distribution is still subject to rationing, the frequency of which varies according to regional water availability and the state of the distribution networks. Supply varies from a few hours a day to a few days a week in some areas. To alleviate shortages, the state often supplies water by tanker to meet daily needs until the distribution network is restored. This practice is particularly evident during the summer season, when high temperatures, increased demand and ageing infrastructure contribute to supply disruptions. While the ultimate goal remains continuous (24/7) water supply, declining rainfall in recent years has exacerbated the challenges, reducing available water levels and straining the distribution system.

With regard to the distribution of drinking water, the sector is managed by several key institutions. *Algérienne des Eaux* (ADE)[2] is responsible for the production and distribution of drinking water in urban areas, while the *Office National de l'Assainissement* (ONA) is in charge of wastewater treatment. In Algiers and Tipaza, water services are managed by SEAAL *(Société des Eaux et de l'Assainissement d'Alger*), a public limited company owned 70% by ADE and 30% by ONA, which provides drinking water and sanitation services. In addition, local water authorities and municipalities play a role in managing water supply in smaller towns and rural areas. This multi-level governance structure aims to improve efficiency and service coverage, although challenges remain in ensuring equitable and continuous water distribution throughout the country.

Overall, Algeria's water sector has made significant progress in infrastructure development and resource management. However, the ongoing problem of water scarcity, exacerbated by climate variability and ageing networks, requires further efforts in conservation, technological innovation and policy reform to ensure long-term water security for all users.

3. Economic analysis of water supply costs

3.1. Technology, service quality, and performance indicators

Water utilities are responsible for extracting raw water from groundwater or surface sources, treating it to meet drinking water standards, and distributing it to consumers. This process involves three basic stages: (1) extraction and treatment, (2) storage and pressurisation, and (3) transmission and distribution. The technological choices and associated costs for each stage vary significantly depending on the specific characteristics of the area served, including the type of water source, user density and topography.

In arid and semi-arid regions such as Algeria and other North African countries, water scarcity is a persistent problem, exacerbated by climate change and increasing demand. Seasonal variations and prolonged droughts often lead to the depletion of reservoirs, resulting in planned or unplanned water

[2] Website ADE: https://www.ade.dz/

cuts. These service interruptions not only affect households, but also have a significant economic impact, affecting agriculture, industry and the overall productivity of the country.

In Algeria, water distribution schedules are often adjusted based on reservoir levels, and prolonged shortages can lead to reduced supply hours, sometimes falling below critical thresholds required for basic needs. The frequency and duration of water cuts highlight the vulnerability of the infrastructure and the need for efficient resource management. Utilities must strike a balance between optimising water distribution, maintaining service quality, and controlling costs. This trade-off is essential in determining policies for investment in network expansion, leakage reduction, and alternative water sources such as desalination or wastewater reuse.

Water scarcity and intermittent supply patterns have both direct and indirect impacts on water costs. Higher operating costs result from the need for contingency measures such as water trucking or additional pumping during peak shortages. Wear and tear on infrastructure also increases as frequent shutdowns and restarts put additional stress on pipes, pumps and treatment plants, accelerating their deterioration and requiring more frequent maintenance and replacement. In addition, the need to develop alternative water sources, such as desalination plants or water reuse systems, involves significant capital investment and higher production costs per cubic metre compared to conventional sources. These higher costs are often passed on to consumers, affecting affordability and access to water services, particularly for low-income populations.

Therefore, a first critical aspect of service performance is the availability of drinking water to users, specific to water scarce regions, often measured by the number of hours of water supply per week. This indicator captures the reliability of the service and is a key determinant of consumer satisfaction. While subjective perceptions of service quality exist, these objective measures provide standardised benchmarks against which to assess performance.

Another critical challenge in water supply management is the existence of water losses due to leakage in the network downstream of the distribution of the volume of water intended for users. This is one of the causes of inefficiency in the system as a whole, leading to inefficiencies that affect both cost and pricing strategies, and in particular a point that should not be overlooked by service managers in terms of the opportunity cost of the volume of water lost, especially in regions where raw water availability is subject to recurrent stress. From a public perspective, water losses are undesirable in the context of resource protection policies, particularly in regions where water is not abundant. The way in which these losses affect the water intended for users has not been fully considered in the economic literature on water utilities until recently (Garcia, 2001; Garcia and Thomas; 2001).

On the part of the water service providers, it is in their interest to take these interactions into account. If they produce a sub-optimal amount of lost water, they are not distributing drinking water at the lowest cost. Therefore, if they want to reduce this type of inefficiency, they need to reduce losses as a function of the amount of water demanded and the cost of preventing losses. Consequently, a key performance indicator for utilities is the water loss rate (percentage of non-revenue water), which reflects the effectiveness of network maintenance and cost control efforts.

Our economic modelling of water supply costs incorporates these variables within a cost function framework. In this approach, the volume of drinking water distributed is treated as the primary output, while performance indicators such as water loss rate and distribution hours are integrated to assess efficiency and service reliability. These are decision variables that allow adjustments in service management and are therefore endogenous (Torres and Morrison Paul, 2006; Destandau et Garcia, 2014). They are influenced by constraints such as technical, environmental, meteorological factors and the availability of water resources, all of which affect both cost structures and management decisions. In regions facing water scarcity and climate variability, optimal management of these parameters becomes crucial to maintain service quality while controlling costs and minimising losses.

3.2. A variable cost function incorporating water scarcity indicators

The cost structure of water utilities can be analysed using a variable cost function that takes into account both the volume of drinking water distributed (y) and key service quality indicators (q), as well as input prices (w), capital variables (K) and other potential exogenous factors affecting costs (z). Given the nature of water utility operations, we define the variable cost function as:

$$VC(y, q, w;\ K, z, t) \tag{1}$$

where VC are the variables costs and t a time trend.

An important factor in our cost framework is water infrastructure capital. This includes the reservoirs and different pipelines. The variable cost function must be non-increasing in infrastructure capital (Chambers, 1988, p.102), meaning that higher fixed capital should not increase variable costs. However, in the long run, fixed capital does not necessarily minimise variable costs. The optimal level of infrastructure investment is determined by the first-order condition:

$$\frac{\partial VC(y, q, w;\ K, z, t)}{\partial K^*} = -w_K \tag{2}$$

where K^* is the optimal level of infrastructure capital, and w_K is its price. If this condition is not met, overinvestment in infrastructure may occur, leading to inefficient cost structures.

From the variable cost function, we can also determine the marginal cost of water supply:

$$\text{MC} = \frac{\partial VC(y, q, w;\ K, z, t)}{\partial y} \tag{3}$$

This allows us to analyse cost variations due to changes in the volume of water distributed. The marginal cost of water supply can vary between utilities depending on factors such as network conditions, water source availability and treatment complexity.

A key aspect of our cost analysis is the relationship between service quality indicators $q$such as water loss rate and distribution hours, and the marginal cost of water supply. We try to assess how variations in these quality indicators affect the marginal cost of distributing drinking water y. Formally, we investigate whether an improvement in service quality reduces the marginal cost of water supply:[3]

$$\frac{\partial^2 VC(y, q, w;\ K, z, t)}{\partial \mathrm{y} \partial q_i} \leq 0 \tag{4}$$

where q_i is one of the service quality indicators, including water loss rate and distribution hours. If this condition holds, then improving network efficiency (e.g., reducing leakage) or increasing service reliability (e.g., extending service hours) reduces the marginal cost of providing drinking water. This would suggest cost complementarities between improvements in service quality and water distribution, meaning that investments in better infrastructure and maintenance lead to operational cost savings.

Conversely, if:

$$\frac{\partial^2 VC(y, q, w;\ K, z, t)}{\partial \mathrm{y} \partial q_i} > 0, \tag{5}$$

this would indicate a cost trade-off where stricter service quality requirements (such as reducing leakage to extremely low levels) increase the marginal cost of water supply. This could be due to higher maintenance costs, energy consumption or capital-intensive interventions required to maintain optimal conditions.

By estimating this relationship, we aim to determine whether policies aimed at improving service quality lead to cost efficiencies or, alternatively, impose additional financial burdens on utilities. Understanding these dynamics is crucial for designing sustainable water management strategies in water-scarce regions such as Algeria, where ensuring both affordability and service reliability is a constant challenge.

4. Econometric strategy

4.1. Econometric specification of the variable cost function

[3] This approach is closely related to Panzar's (1989) definition of weak cost complementarities between two outputs, as it examines whether improving service quality indicators reduces the marginal cost of water distribution, similar to how complementarities between outputs reduce the marginal cost of production.

For the econometric specification of the variable cost function, we chose the translog functional form (Christensen et al., 1971, 1973). This functional form has the advantages of being (i) flexible, (ii) easy to compute, and (iii) it easily allows the imposition of linear homogeneity in input prices, by dividing variable cost and input prices by the price of one of the inputs.[4] If we arbitrarily choose one of the input prices as being the reference (let us note it as w_D), then the specification of the translog variable cost function can be written as:

$$\begin{aligned}\ln\left(\frac{VC}{w_D}\right) = {} & \beta_0 + \beta_y \ln(y) + \sum \beta_i \ln(q_i) + \sum \beta_j \ln\left(\frac{w_j}{w_D}\right) + \sum \beta_k \ln(K_k) + \tfrac{1}{2}\sum \beta_{yy}[\ln(y)]^2 \\ & + \tfrac{1}{2}\sum\sum \beta_{ii'} \ln(q_i)\ln(q_{i'}) + \tfrac{1}{2}\sum\sum \beta_{jj'} \ln\left(\frac{w_j}{w_D}\right)\ln\left(\frac{w_{j'}}{w_D}\right) \\ & + \tfrac{1}{2}\sum\sum \beta_{kl} \ln(K_k)\ln(K_l) + \sum \beta_{yi} \ln(y)\ln(q_i) + \sum \beta_{yj} \ln(y)\ln\left(\frac{w_j}{w_D}\right) \\ & + \sum \beta_{yk} \ln(y)\ln(K_k) + \sum\sum \beta_{ij} \ln(q_i)\ln\left(\frac{w_j}{w_D}\right) + \sum\sum \beta_{jk} \ln\left(\frac{w_j}{w_D}\right)\ln(K_k) \\ & + \sum\sum \beta_{ik} \ln(q_i)\ln(K_k) + \beta_t t + \beta_{tt} t^2 + \beta_{yt}\ln(y)t + \sum \beta_{it} \ln(q_i)\, t\end{aligned} \tag{6}$$

The set of parameters (β_0, β_y, β_i, β_j, β_k, β_{yy}, $\beta_{ii'}$, $\beta_{jj'}$, β_{kl}, β_{yi}, β_{yj}, β_{yk}, β_{ij}, β_{jk}, β_{ik}, β_t, β_{tt}, β_{yt}, β_{it}) must be estimated. Since the cost function is twice differentiable, its Hessian matrix must satisfy the following symmetry restrictions: $\beta_{ii'} = \beta_{i'i}$, $\beta_{jj'} = \beta_{j'j}$, $\beta_{kl} = \beta_{lk}$. For the sake of simplicity, we have omitted the variables z declared in equation (1), as we do not have any additional variables that could enter directly into the variable cost function. However, our estimation procedure takes into account the possible existence of omitted variables, which we will return to later in this article. Note also that since $\ln\left(\frac{VC}{w_D}\right) = \ln(VC) - \ln(w_D)$, it is equivalent to regressing $\ln(VC)$ on the regressors mentioned in equation (6), and having a new intercept $c = \beta_0 + \ln(w_D)$. Hence, by denoting TL, the translog function, equation (6) can now be written in a simplified form as:

$$\ln(VC) = \mathrm{TL}\left(y, q_i, \frac{w_j}{w_D};\ K_k, t\right) \tag{7}$$

The translog specification therefore allows us to calculate marginal costs, cost complementarities and returns to scale.

4.2. Mundlak estimation model for panel data

[4] The homogeneity of degree one can be equivalently imposed by a set of constraints on the parameters of the variable cost function: $\sum \beta_j = 1$, $\sum_j \beta_{jj'} = \sum_{j'} \beta_{jj'} = 0$, $\sum_j \beta_{yj} = \sum_j \beta_{ij} = \sum_j \beta_{jk} = 0$. When parametric identification is not straightforward, as in the case of maximising a likelihood function, it is also possible to use an estimation method based on the minimum distance between an unconstrained and a constrained model, see for example Chiappori et al. (2018).

The panel dataset combines cross-sectional and time dimensions, capturing the behaviour of 75 water services in Algeria observed over 20 quarters (five years), see the presentation of data below. This structure helps to account for both individual (utility-specific) and aggregate (time-dependent) factors, while allowing for unobserved heterogeneity. In particular, the inclusion of individual-specific effects in the econometric model is a way to control for the presence of unobserved (time-invariant) individual heterogeneity, which may be correlated with some of the explanatory variables in the model, and to avoid endogeneity bias, especially in the common case of short panels. In the context of estimating the structural parameters of the technology used in water utilities, the management quality of each service in economic and operational terms is usually an unobservable part of managers' preferences.

We model the cost function as:

$$\ln(VC_{nt}) = \mathrm{TL}\left(y_{nt}, q_{int}, \frac{w_{jnt}}{w_{Dnt}};\ K_{knt}, t\right) + \alpha_n + u_{nt} \tag{8}$$

where α_n represents unobserved individual-specific effects (e.g., management quality), and u_{nt} captures idiosyncratic errors. These individual effects may be correlated with the explanatory variables, potentially introducing endogeneity bias. This approach allows us to incorporate both time-varying and time-invariant characteristics of the 75 water services observed over 20 quarters in Algeria, ensuring a robust estimation of cost structures and efficiency determinants.

In the case of panel data, it is well known that the fixed effects (FE) approach eliminates individual-specific effects (α_n) by transforming variables into deviations from their means. However, this method cannot estimate coefficients for time-invariant variables. Instead, the random effects (RE) approach assumes that the α_n are uncorrelated with the explanatory variables, allowing the estimation of both time-varying and time-invariant coefficients. To take advantage of both approaches, we consider the correlated random effects (CRE), see Krishnakumar (2006).

Consider a panel linear model where α_n is the unobserved individual heterogeneity, with $E(\alpha_n | y_{nt}, q_{int}, \frac{w_{jnt}}{w_{Dnt}};\ K_{knt}) \neq 0$ but assuming no correlation with the potential time-invariant capital variables K_{kn}: $E(\alpha_n |\ K_{kn}) \neq 0$. Mundlak (1978) showed that the FE model is equivalent to the RE model that includes the means of the time-varying explanatory variables in addition to the full set of explanatory variables (possibly including time-constant variables), and thus the within-estimator remains valid in the CRE approach (Wooldridge, 2010).

Following Mundlak (1978), we model the individual specific effect as potentially correlated with time-varying explanatory variables such that:

$$\alpha_n = TL\left(\overline{y_n}, \overline{q_{in}}, \frac{\overline{w_{Jn}}}{w_{Dn}};\ \overline{K_{kn}}; \alpha\right) + a_n \tag{9}$$

where a bar above a variable denotes its individual mean, i.e., the average over time (e.g., $\overline{y_n} = {}^{1}/_{T_i} \sum_t y_{nt}$). The paramaters α associated with the individual means of the time-varying explanatory variables are to be estimated.

This model can be estimated using pooled OLS, which gives consistent estimates. However, the structure of u_{nt} may introduce new problems of heteroskedasticity and serial correlation. Therefore, it is desirable to correct the estimated standard errors for the structure in each cluster. This method allows us to apply a simple robust like-Hausman test in our CRE framework, which consists of testing the null of the estimated parameters associated with the means of the time-varying explanatory variables.

4.3. Dealing with idiosyncratic endogeneity with control functions

Our study aims to identify the key determinants of water service costs and the decision-making process behind certain operational variables. To achieve this, we estimate a variable cost function that captures the effects of several factors, including the volume of drinking water distributed, the drinking water loss rate, and the number of service hours per week. These latter variables are likely to be endogenous in the cost equation.

Endogeneity may arise because these variables are not purely exogenous determinants, but rather continuous choice variables influenced by both technical constraints (such as production conditions and network infrastructure) and external environmental factors (including temperature and rainfall). In particular, service providers adjust water distribution volumes, supply hours and leakage management in response to demand fluctuations and operational constraints, which may be correlated with unobserved cost determinants. Ignoring this endogeneity could lead to biased and inconsistent parameter estimates in the cost function.

To address this issue, we use a control function approach, which allows us to correct for endogeneity by modelling the unobserved components of the endogenous regressors. In this framework, we first estimate reduced-form equations for each endogenous variable using appropriate instrumental variables. Meteorological factors, such as temperature and rainfall, serve as valid instruments because they directly affect water supply and demand conditions, but do not directly affect costs beyond their impact on these decision variables. The residuals from these first-stage regressions are then included as additional regressors in the estimation of the main cost function, effectively capturing the endogeneity bias and ensuring more reliable parameter estimates. This methodological approach enhances the robustness of our cost function estimation, provides a clearer understanding of how utilities make operational decisions under environmental constraints, and allows for more accurate policy recommendations regarding cost efficiency and resource allocation.

The first step in our empirical strategy is therefore to estimate these reduced-form equations (the control functions). We consider an equation for each of the three endogenous variables (summarised in the vector Y) in which we regress the volumes of water distributed, the water loss rate and the number of service hours on the exogenous explanatory variables of the variable cost function and additional instrumental variables. These variables are estimated in the framework of the translog specification, so that the general control equation can be written as

$$\ln(Y_{nt}) = \mathrm{TL}\left(\frac{w_{jnt}}{w_{Dnt}}, K_{knt}, I_{gnt}\right) + \theta_n + v_{nt} \tag{10}$$

where g indexes the different instrumental variables I used in the control functions, θ_n is the water service specific effect and v_{nt} is an idiosyncratic error. These control functions are estimated using the CRE approach, as we do for the cost equation. Therefore, these equations, augmented by the set of individual means of the exogenous variables, are also estimated by pooled OLS, which gives consistent estimates. Again, because the structure of v_{nt} introduces potential potential problems of heteroskedasticity and serial correlation, we adjust the standard errors for each infividual cluster.

Finally, we can obtain the three residuals $\widehat{v_{nt}}$ to enter into the cost equations in the second stage to correct for the potential endogeneity of each of the three decision variables. These new variables will have to be considered in the whole CRE framework and will be accompanied by their own individual means.

Hence, given the limited number of water services in our study (66 individuals) and the two-stage nature of our estimation procedure, we use bootstrapping to correct for potential bias in standard errors. To ensure robust statistical inference, we use wild cluster bootstrap inference, implemented through the boottest package in Stata (Roodman et al., 2019). This approach provides reliable p-values and t-statistics that account for the small number of clusters, while also accounting for the introduction of residuals from the control function, which corrects for the endogeneity of the output and quality variables in the two-stage estimator. Furthermore, we adopt a conservative approach by implementing a multiway clustering strategy that takes into account both individual and temporal dimensions.

5. Empirical application

5.1. Data

We collected data from 75 Algerian municipalities in two wilayas[5], namely Algiers and Bejaia. The operator, *Algérienne des Eaux* (ADE), is responsible for the supply of drinking water at the commune level, which is therefore the statistical unit of observation for the purposes of empirical analysis. All data were collected from this operator at the wilaya level, with the exception of some meteorological data, namely temperature and rainfall, which were provided by the Meteo-Algeria service.

[5] The wilaya is a local authority roughly equivalent to a French department.

Most of this data comes from reports prepared by the various water agencies in each wilaya, based on the technical, accounting and financial reports prepared quarterly by the managers of the water production and distribution services. These reports include information on the various costs of production factors and chemicals, technical information on the network, and the volumes of water produced and distributed. These balances also include the consumption of electricity in kilowatts and in value, the salaries of the different categories of staff (managers, supervisors and operators) and the corresponding number of employees. Most of this data relates to municipalities with drinking water supplies and is available from the wilaya. As some of these data are only available at the aggregate level of the wilaya, we had to use a disaggregation method at the commune level that was as appropriate as possible, given the information we obtained on the practices of ADE managers through interviews with some of this operator's managers at the wilaya level.[6]

The data used are quarterly and cover a 5-year period from the first quarter of 2010 to the fourth quarter of 2014. They correspond to the 20 quarters of this period. Our sample therefore consists of 1,500 observations on 75 municipalities whose drinking water supply service is managed by the ADE.

The volume of drinking water distributed (dist_vol) is obtained as the volume of water distributed to households through the distribution network. The volume of water lost (lost_vol) is calculated as the difference between the volume of drinking water produced (prod_vol) and the volume distributed to households. All water volumes are expressed in m3. A widely used performance indicator is the loss rate, which is calculated as the ratio between the volume lost and the volume produced. It's important to remember that the quantities produced, distributed and lost vary, sometimes considerably, according to the state and type of network (supply or distribution). Another important variable in the context of water scarce Mediterranean countries is the distribution time slots, calculated as the total number of hours of service during the week (hourweek). This last variable is used to characterise the quality of the drinking water distribution service.

We calculate operating costs as variable costs (VC) as the sum of the costs of labour, energy and chemical products used to treat raw water. The unit of currency is the Algerian Dinar (DZD).[7] The cost of labour (including wage costs) expressed in DZD is obtained by adding the cost shares of three categories, i.e. managers, workers and supervisors. The unit price of labour (w_l) is the sum of labour costs divided by the number of different wage categories. The unit price of energy (w_e) is calculated as the ratio between the cost of electricity and energy consumption and is expressed in DZD/kWh. The cost of chemical products is made up of several cost elements grouping together the different products used (disinfectants, calcium hypochlorite and sodium hypochlorite; detergents, alumina sulphate; detergents, polymer and carbon; and antibacterial, antimicrobial and anti-organic agents, chlorine). We

[6] This is the case for production factors such as labour and chemicals, which can only be observed at the level of each wilaya, and therefore aggregated for all the communes in that wilaya.
[7] Over the period 2010-2014, 1 DZD = 0.0095€ on average.

used the expenditure for each of the chemical products, expressed in DZD/kg, in the same way as the labour input costs.

The capital variables are: the length of the distribution network (length_dist) and the supply network (length_supply) in kilometres, the production capacity (cap_prod) in m3/hour, the storage capacity (cap_store) in m3 and the pumping capacity (cap_pump) in m3/hour. However, we do not use this last variable due to too many missing observations. Table 1 provides descriptive statistics of the variables making up the database used.

Table 1. Descriptive statistics of drinking water services

Variable	Description (Unit)	N	Mean	SD	Min	Max
VC	Variable costs (in thousands of DZD)	1500	80,008,973	472,104,147	128.13	6,500,734,464
prod_vol	Volume of drinking water produced (m3)	1500	867,143	867,844	10,470	7,812,563
dist_vol	Volume of drinking water distributed to customers (m3)	1500	581,557	591,357	7289	5497260
lost_vol	Water losses (m3)	1500	285,586	279,807	3181	2652673
loss_rate	Water loss rate (%)	1500	0.3325	0.0327	0.1701	0.4064
hourweek	Total hours of water supply per week	1500	137.98	44.27	9.93	168.00
we	Electricity price (DZD/kWk)	1500	3.1645	0.2635	2.9800	4.2745
wl	Labour price (DZD/quarter)	1500	77,715	38,992	0.2776	124,742
wc	Prices for chemical products (DZD/kg)	1500	218.60	334.81	1.2658	1,314.80
pop_serv	Population served by the distribution network (inhabitants)	1500	50,298	47,055	3,373	1,111,856
connect	Number of household connections	1500	9,029	7489	354	51,814
length_supply	Length of supply network (metres)	1460	10,244	18495	75	145,562
length_dist	Length of distribution network (metres)	1480	60,873	51,506	5,000	323,000
cap_prod	Hourly production capacity (m3⁄hour)	1340	324.80	333.22	2.28	2,982.22
cap_pump	Hourly pumping capacity (m3⁄hour)	1100	2,118.79	3,790.94	50	21,355
cap_store	Storage capacity (m3)	1380	11,367	20,037	49.92	133,616

Meteorological variables: rainfall and temperature. These last two variables are expressed in millimetres (mm) and degrees Celsius (°C) respectively, and allow us to characterize the availability or deficit of water production in the two sample wilayas in our geographical area. The considerable drop in rainfall has led to a fall in dam levels and the drying up of several springs and boreholes, while the high demand for water is linked to hot weather, the dilapidated state of supply and distribution networks, and illicit connections have led to a considerable loss of water. The focus here is on meteorological variables, over several periods of time, which will be used as instrumental variables. Note that we consider that past meteorological events can have an impact of the present, tis is why we also collect data do the year 2009, explaining a number of observations equal to 1800. These data are presented in Table 2.

Table 2. Descriptive statistics of meteorological data

Variable	Description (Unit)	N	Mean	SD	Min	Max
Rainfall	Rainfall (in mm)	1800	63.41	40.06	2.45	162.73
Temperature	Temperature (in Celsius degree)	1800	18.17	4.80	10.20	25.93

5.2. Empirical results

The translog specification used for the variable cost function is a second-order Taylor series expansion that approximates the variable cost function (in logarithms) around a chosen reference point. To ensure the validity of this local approximation (White, 1980), we take the sample mean of the variables (in logarithms) as the reference. Consequently, all right-hand-side variables are normalised by their respective sample means (mean scaling), allowing the first-order coefficients of outputs and inputs to be interpreted directly as cost elasticities evaluated at the sample mean of our Algerian water utilities dataset.

As control functions are used to correct for endogeneity in the cost function, we will first examine whether this correction is relevant before interpreting the final results of the cost function. The variables used to estimate the control functions are also mean-scaled.

5.2.1. Estimation of the control functions

Some of the key decision variables in our cost function, such as the number of service hours per week, the volume of drinking water distributed, and the water loss rate, are likely to be endogenous in the variable cost function. These variables are determined not only by managerial decisions but also by technical constraints and external environmental factors, such as climatic conditions. Endogeneity arises when unobserved factors, such as management quality or infrastructure conditions, simultaneously affect both the cost structure and these decision variables, leading to potential estimation bias.

To address this issue, we use a control function approach, which explicitly models the endogenous variables as functions of exogenous determinants, including instrumental variables. In our case, we use meteorological variables (e.g. temperature and rainfall) but also the total population of the municipality as instruments, along with other exogenous factors, to explain the variation in the endogenous variables. The residuals from these auxiliary regressions are then included as additional regressors in the cost function estimation to capture the portion of endogeneity that would otherwise bias the coefficients. This approach allows us to obtain consistent estimates of the cost function parameters while taking into account the underlying determinants of decision variables that are not directly observed. The results of the control function estimations are presented in Table A1 in Appendix and confirm the relevance and significance of the instruments chosen.

The estimation results for the control functions highlight the strong influence of meteorological variables, infrastructure characteristics and operational constraints on the endogenous variables. Rainfall and temperature, both contemporaneous and lagged, significantly affect service hours, volume distributed and water loss rate. First, we can see that higher rainfall has a strongly significant positive effect on the number of service hours, confirming the crucial role of rainfall in the continuous supply of drinking water to households. However, higher rainfall generally leads to a reduction in service hours and volume distributed, with significant negative effects at different lags, while its effect on the water loss rate remains largely insignificant. At first sight, this result may seem unexpected. However, after heavy rainfall, household demand temporarily decreases as rainwater collection and reduced outdoor water use (e.g., for cleaning or gardening) reduce network consumption, particularly in areas equipped with tanks or rainwater collection systems. In response, water utilities may adjust distribution schedules to optimise resource management. In addition, rainfall can affect network hydraulics by changing pressure dynamics, and in some cases water infiltration into ageing pipes can cause localised disruptions. However, such impacts on infrastructure remain limited in Algeria, where water supply is primarily based on groundwater rather than surface sources. Temperature, on the other hand, has a strong negative effect on service hours and volume distributed, suggesting that higher temperatures decrease demand while limiting supply capacity. At the same time, higher temperatures contribute to decreased water losses.

In addition to climatic factors, the characteristics of the population served and infrastructure variables play a crucial role in water service decisions. The interaction between population size and network characteristics such as production and storage capacity has a significant effect on volume distributed, but a weaker effect on service hours and water losses. Larger production capacity is strongly associated with higher distributed volumes, confirming its role in meeting demand, but has no significant effect on water loss. Storage capacity has a positive effect on volume distributed, but no clear effect on service hours or losses.

Network structure and operational constraints also influence these results. Longer supply networks are associated with an increase in hours of service but a decrease in volume distributed, suggesting possible inefficiencies or supply constraints over longer distances. While the number of connections mechanically increases distributed volume, the density of connections relative to network length (length_dist) has a negative effect on distributed volume, suggesting that more densely connected areas face supply constraints. Note that we find an inverse result regarding the interaction term between the population served and the upstream network (length_supply).

Overall, the results confirm the validity of meteorological variables as instrumental variables, as they significantly influence the endogenous variables in the expected directions. They also emphasise the importance of infrastructure and operating conditions in shaping service provision. These findings reinforce the need for a control function approach to account for endogeneity in cost function estimation,

5.2.2. Estimation of the variable cost function

Table 3 presents the results of the estimation of the translog cost function using two different approaches. The first three columns correspond to the estimation based on the CRE approach, which includes the individual means of the time-varying explanatory variables. This allows us to control for correlation with individual effects, effectively providing fixed effects estimates for these coefficients. The last three columns present the results also obtained from the CRE approach, but using an IV estimation method based on the control function approach, whose results are commented on in the previous subsection, which accounts for idiosyncratic endogeneity. Specifically, the correlation between output (dist_vol) and performance variables (loss_rate and hourweek) with the idiosyncratic error term is corrected.

Table 3. Estimation results of the variable cost function

	CRE approach			CRE approach with IV method		
Variables	coef	tstat	pval	coef	tstat	pval
dist_vol	0.5653***	7.7523	0.0000	0.7904***	9.2285	0.0000
loss_rate	0.4531***	3.0023	0.0045	0.4863***	3.3180	0.0027
hourweek	0.1027*	2.0362	0.0569	0.1099**	2.1992	0.0429
connect	0.0111	0.1810	0.8689	0.0930	0.9630	0.3890
hwe	1.7493***	57.6203	0.0000	1.7901***	66.4324	0.0000
hwl	-0.8476***	-38.8236	0.0000	-0.8701***	-43.7341	0.0000
length_supply	-0.0001	-2.3763	0.2600	-0.0003	-2.8623	0.2191
length_dist	0.0004**	4.6001	0.0250	0.0005**	5.2885	0.0280
cap_prod	0.3568***	6.7423	0.0000	0.7415***	9.6596	0.0000
cap_store	0.0151	0.6743	0.5842	0.0084	0.2984	0.8016
$(\text{dist\_vol})^2$	0.4332**	2.9347	0.0272	0.3501**	2.5022	0.0452
$(\text{loss\_rate})^2$	0.4842	0.9026	0.3847	0.4861	0.9506	0.3567
$(\text{hourweek})^2$	0.0333	0.4713	0.7086	0.0386	0.6649	0.5635
$(\text{connect})^2$	-0.1952	-1.5264	0.2265	-0.1186	-0.8708	0.4691
$(\text{hwe})^2$	-0.0170	-1.0680	0.2837	0.0156	1.3017	0.1928
$(\text{hwl})^2$	-0.0017*	-1.5968	0.0994	-0.0004	-0.4663	0.6197
$(\text{length\_supply})^2$	-0.0001	-3.5196	0.1084	-0.0002	-3.1007	0.1553
$(\text{length\_dist})^2$	0.0004	2.9596	0.1456	0.0006*	4.0148	0.0958
$(\text{cap\_prod})^2$	0.0935	1.7448	0.1956	-0.1916**	-3.1230	0.0327
$(\text{cap\_store})^2$	0.0030	0.3758	0.7428	0.0124	0.8981	0.4367
we_x_wl	0.0477***	5.1367	0.0000	0.0370***	4.8159	0.0000
dist_vol_x_loss_rate	-1.5922***	-6.0307	0.0002	-1.4440***	-5.1237	0.0019
dist_vol_x_hourweek	-0.2383**	-2.9133	0.0222	-0.1885**	-2.7708	0.0268
dist_vol_x_we	-0.0004	-0.0228	0.9847	-0.0093	-0.6417	0.5693
dist_vol_x_wl	-0.0003	-0.0877	0.9354	0.0062	1.6480	0.1286
dist_vol_x_connect	-0.1392	-2.0433	0.1302	-0.1537*	-1.9223	0.1565
loss_rate_x_hourweek	0.1083	0.6476	0.5653	0.0687	0.4491	0.6837
loss_rate_x_we	0.0283	0.4589	0.6558	0.0508	0.7827	0.4539
loss_rate_x_wl	-0.0013	-0.0565	0.9558	-0.0094	-0.4193	0.6753
loss_rate_x_connect	0.4392***	3.8093	0.0013	0.4612***	3.0239	0.0067
hourweek_x_we	0.1059***	3.2745	0.0057	0.0961***	3.1218	0.0074
hourweek_x_wl	-0.0669**	-2.7464	0.0128	-0.0599**	-2.5533	0.0204
hourweek_x_connect	0.1077	1.7460	0.1450	0.1275*	2.1082	0.0742
connect_x_we	0.0151	0.8815	0.4252	0.0266	1.5584	0.1675

connect_x_wl	-0.0019	-0.5316	0.6259	-0.0076*	-1.9838	0.0652
dist_vol_x_cap_prod	-0.2939**	-3.3628	0.0104	-0.1139	-1.2811	0.2574
dist_vol_x_cap_store	-0.1269**	-2.6701	0.0182	-0.1956***	-3.4290	0.0034
loss_rate_x_cap_prod	1.1978***	4.4660	0.0023	1.0571***	3.8797	0.0062
loss_rate_x_cap_store	-0.0017	-0.0520	0.9604	-0.0055	-0.1799	0.8576
hourweek_x_cap_prod	0.1708**	2.6305	0.0466	0.0915*	2.1402	0.0843
hourweek_x_cap_store	0.0215	1.8851	0.1730	0.0367	2.3334	0.1028
connect_x_length_supply	0.0987***	3.2394	0.0057	0.1512**	2.3414	0.0332
connect_x_length_dist	-0.0322	-0.3635	0.7662	-0.1131	-0.8299	0.5096
connect_x_cap_prod	0.1968*	2.3039	0.0831	0.2421*	2.2004	0.0874
connect_x_cap_store	0.0711	1.6928	0.1284	-0.0479	-1.0859	0.3335
length_supply_x_length_dist	0.0933	1.1751	0.5345	-0.1763	-1.1501	0.4725
cap_prod_x_cap_store	0.1043	1.8642	0.1106	0.2393***	3.7185	0.0017
cap_prod_x_length_supply	-0.0311	-1.9300	0.1130	-0.0310	-1.1779	0.2930
cap_prod_x_length_dist	0.0261	0.4906	0.6657	0.0986	1.6876	0.1523
cap_store_x_length_supply	-0.0019	-0.1863	0.8775	0.0301	1.4664	0.2244
cap_store_x_length_dist	-0.0934	-1.8681	0.2740	-0.1300	-2.2615	0.1380
t	0.0807***	27.3846	0.0000	0.1021***	15.9536	0.0000
t^2	-0.0025***	-24.8107	0.0000	-0.0030***	-18.8792	0.0000
dist_vol_x_t	0.0003	0.2728	0.7934	0.0018	1.5735	0.1602
loss_rate_x_t	-0.0023	-0.2181	0.8264	-0.0047	-0.4514	0.6505
hourweek_x_t	-0.0078***	-3.0988	0.0086	-0.0075**	-2.6665	0.0187
hourweek_hat				-0.3703**	-2.6640	0.0129
dist_vol_hat				-0.8889***	-9.7706	0.0000
loss_rate_hat				0.0744	0.3718	0.7057
Constant	15.0893***	418.3324	0.0000	14.8210***	270.4441	0.0000

Notes. Obs. = 1,320. Number of services = 66.
CRE approach means that the individual means of time-varying explanatory variables are included.
T-stats and P-values are bootstrapped with the boottest package (Roodman et al., 2019) using the bootcluster() option to control the level of bootstrap clustering on the service and time dimensions.

We performed a Fisher test on the coefficients of the individual means for each estimation method. The results significantly reject the null hypothesis of the nullity of the coefficients, indicating the presence of heterogeneity related to the correlation of the individual effects, which justifies the use of a CRE approach. Furthermore, the significance tests on the residual coefficients of the control functions (hourweek_hat, dist_vol_hat and loss_rate_hat) confirm the rejection of the exogeneity assumption for the two variables hourweek and dist_vol. This suggests that the chosen estimation method, the combination of a CRE approach and an IV estimation method, is particularly well suited to address endogeneity concerns in this context.

A comparison of the first-order coefficients between the two approaches reveals some notable differences.[8] For example, the estimated coefficient of dist_vol increases from 0.5653 in the CRE model to 0.7904 in the CRE-IV model, suggesting that ignoring endogeneity leads to an underestimation of the cost elasticity with respect to output. Similarly, the coefficient of loss_rate increases from 0.4531 to 0.4863, while hourweek shows a slight increase from 0.1027 to 0.1099, reinforcing the idea that these variables were likely downward biased in the CRE estimation. While the increasing marginal cost of drinking water distribution is trivial, other results may appear less so. Higher water loss rates increase

[8] We will not spend time discussing price elasticities and input substitution, as this analysis has been carried out in detail by Zeggagh and Mazouz (2024).

production costs due to additional water treatment and distribution requirements. Similarly, an increase in weekly distribution hours can increase operating costs due to energy consumption and labour costs.

The estimated coefficients of input prices provide insight into the cost structure and input substitution patterns. From the CRE_IV estimation results, the significantly positive coefficient of ln(we/wc) (1.7901) suggests that an increase in the price of electricity relative to the price of chemicals leads to a significant increase in variable costs, indicating a strong dependence on electricity in the production process. Conversely, the negative coefficient of ln(wl/wc) (-0.8701) implies that higher labour costs relative to chemical prices are associated with a lower cost impact, possibly reflecting a substitution effect where labour can be replaced by other inputs, or a lower cost share of labour in the overall production process.

Other key production and cost-related variables, such as cap_prod, also show significant increases in their coefficients under the IV specification, growing from 0.3568 to 0.7415, highlighting the impact of controlling for endogeneity. This positive coefficient (significantly different from zero at the 1% level) suggests that a 1% increase in hourly production capacity implies a 0.74% increase in variable costs. This implies that larger utilities benefit from cost efficiencies, possibly due to the spreading of operating costs over a larger volume of output or improved efficiency in resource utilisation.

Among the capital-related variables, only length_dist (distribution network length) has a statistically significant effect on costs, with a coefficient of 0.0005 (at the 5% level). Recall that, according to production economic theory (Chambers, 1988), the variable cost function should be non-increasing with infrastructure capital. This result thus contradicts this expected cost-reducing effect. A possible explanation is that network expansion is not fully optimised, leading to additional maintenance costs, leakage problems or inefficient operational scaling. If the first-order condition for optimal capital investment is not met (i.e., $\partial VC/\partial K > -w_K$), this may indicate excessive infrastructure expansion relative to actual demand. On the other hand, length_supply (length of supply network) has a negative but insignificant coefficient (-0.0003), suggesting that changes in supply infrastructure do not have a robust effect on variable costs. Similarly, cap_store (storage capacity) has a positive but not significantly different from zero, meaning that larger storage capacity does not significantly affect variable costs.

The estimated coefficients of the time trend variables (t and t^2) provide insight into the evolution of cost structures over time. The coefficient of t is significantly positive (0.1021, $p < 0.01$), indicating that costs have increased over time. However, the negative and highly significant coefficient on t^2 (-0.0030, $p < 0.01$) indicates a decelerating trend in cost growth. This could reflect improvements in efficiency, technological advances or policy interventions that have reduced cost increase. Regarding the interaction terms, the coefficient of dist_vol_x_t (0.0018, $p = 0.16$) is not significantly different from zero, suggesting that the effect of time on the cost elasticity of distributed water volume is weak or negligible. Similarly, the coefficient of loss_rate_x_t (-0.0047, $p = 0.65$) is also not significantly different from zero, indicating that cost variations associated with water losses have not changed significantly over time. In contrast, the interaction term hourweek_x_t (-0.0075, $p < 0.05$) is significantly negative. This suggests that the marginal cost associated with increasing service hours has decreased over time. This could be due to improvements in operational efficiency, better resource management, or infrastructure investments that have reduced the cost burden of extending service hours.

5.2.3. Trade-offs and synergies in water supply management

Understanding the interactions between key cost drivers is essential to improving the efficiency of water supply management. In network industries such as water supply, different operational choices can lead either to cost synergies, where increasing one factor reduces the marginal cost of another, or to trade-offs, where increasing one factor increases the cost of another. Regarding the interaction terms, several cross effects involving dist_vol, loss_rate, hourweek and cap_prod are particularly relevant. As shown by Fuss and Waverman (1981, p. 297) the cross-partial derivative of the variable cost with respect to some key variables can be rewritten as follows:

$$\frac{\partial^2 VC}{\partial y_i \partial y_j} = \frac{VC}{y_i y_j}\left(\frac{\partial lnVC}{\partial lny_i}\frac{\partial lnVC}{\partial lny_j} + \frac{\partial^2 lnVC}{\partial lny_i \partial lny_j}\right) \quad (11)$$

These interactions can be assessed using cross-partial derivatives of the variable cost function, which reveal the existence of trade-offs or synergies in water supply management. Since the first term $VC/y_i y_j$ is positive, the sign of the term between brackets determines the nature of the relationship: a value of zero indicates no interaction, a significant negative sign indicates synergies through cost complementarity, while a significant positive sign highlights trade-offs, where increasing one variable increases the marginal cost of the other.

Table 4 presents our results on these cost interactions, estimated using the CRE-IV model (Table 3) and evaluated at the sample mean of the explanatory variables.

Table 4. Trade-offs and synergies in water supply management

Interaction Term	Coef	Z-stat	P-value
dist_vol × loss_rate	***-1.0597***	***-3.36***	***0.001***
dist_vol × hourweek	-0.1016	-1.49	0.135
dist_vol × cap_prod	***0.4722***	***4.22***	***0.000***
loss_rate × hourweek	0.1222	0.78	0.436
loss_rate × cap_prod	***1.4177***	***4.92***	***0.000***
hourweek × cap_prod	***0.1729***	***2.92***	***0.003***

Notes. Estimates based on those in Table 3.
Standard errors are computed using the delta method with the nlcom command after applying the cluster correction for water services.
Values in bold italics are significantly different from 0.

First, the significantly negative interaction between dist_vol and loss_rate suggests that increasing the volume of distributed water is associated with a lower marginal cost of leakage reduction. This finding is in line with the results already found in several studies (Garcia and Thomas, 2001, in France;

Destandau and Garcia, 2014, in the United States; Zeggagh and Mazouz, 2024, in Algeria), which highlight a common management strategy in water utilities: prioritising higher water production over investing in network maintenance to reduce leaks. This trade-off arises because repairing leaks represents an additional short-term input cost, while increasing water supply allows utilities to meet demand without directly addressing network inefficiencies. However, this approach neglects the opportunity cost of lost drinking water, which can be particularly critical in water-scarce regions where each unit of non-revenue water represents a significant economic and environmental cost.

Second, the interaction between distributed water volume (dist_vol) and production capacity (cap_prod) is significantly positive, indicating that increasing the volume of water produced per hour increases the marginal cost of water distribution. Similarly, the significantly positive interaction between loss_rate and cap_prod suggests that an increase in production capacity increases the marginal cost of water losses. This finding highlights the inefficiency of a strategy that prioritises production over leakage control, and the need for a more integrated approach to resource management, where network maintenance and leakage reduction are seen as essential components of cost minimisation and long-term sustainability.

Finally, the interaction between total hours of water supply per week (hourweek) and production capacity (cap_prod) is significantly positive. This finding suggests that water availability is a constraint, as increasing hours of supply often requires extracting water at a higher marginal cost, either through deeper groundwater pumping, reliance on alternative sources, or increased energy costs. In such cases, efficient water pricing and demand management policies become critical to balancing continuity of supply with cost efficiency.

5.2.4. Assessing Cost Economies and Network Efficiency

In network industries, the assessment of cost economies provides valuable insights into operational efficiency and potential areas for cost reduction. Similar studies have been carried out in the electricity (Roberts, 1986) and water (Garcia and Thomas, 2001; Torres and Morrison Paul, 2006) sectors. Table 5 presents key cost elasticity estimates and network efficiency measures calculated from the estimated parameters by CRE-IV in Table 3 and evaluated at the sample mean of the explanatory variables.

Table 5. Estimated cost elasticities and network economies ($\boldsymbol{H0}$: constant returns $= \mathbf{1}$)

Cost measure	value	T-stat	P-value
$\boldsymbol{\varepsilon_{VC/cap\_prod}}$	***0.7415***	***-3.3673***	***0.0036***
$\boldsymbol{\varepsilon_{VC/dist\_vol}}$	***0.7904***	***-2.4469***	***0.0224***
$\boldsymbol{\varepsilon_{VC/connect}}$	***0.0930***	***-9.3971***	***0.0000***
$\varepsilon_{VC/dist\_vol} + \varepsilon_{VC/connect}$	0.8834	-0.8066	0.4667

Notes. Cost measures estimated at the sample mean.
T-stats and P-values are bootstrapped with the boottest package (Roodman et al., 2019) using the bootcluster() option to control the level of bootstrap clustering on the service and time dimensions.
Values in bold italics are significantly different from 1.

Economies of production are measured by the cost elasticity with respect to the production capacity of the production facilities $\varepsilon_{VC/cap\_prod}$. The value found (0.7415) is significantly lower than 1, indicating economies of scale in water production. This means that an increase in production capacity leads to a proportionally smaller increase in variable costs, reflecting efficiency gains at higher production levels. Economies of volume are measured by the cost elasticity of distributed volume $\varepsilon_{VC/dist\_vol}$. It is calculated to be 0.7904, indicating the existence of economies of scale in water distribution (significantly different from 1 at the 5% level). This result suggests that as utilities distribute more water, average variable costs decrease, possibly due to the fact that fixed infrastructure is spread over a larger output. The cost elasticity $\varepsilon_{VC/connect} = 0.0930$ is significantly lower than 1, indicating strong savings associated with the number of connections (or the number of households connected to the water supply network). Increasing the number of connections leads to a very small increase in variable costs (i.e., a 1% increase in the number of connections leads to a 0.093% increase in costs), meaning that utilities can achieve cost savings by expanding the customer base within existing networks and with a fixed volume of water distributed. The economies of connection density are calculated as the sum of the cost elasticities for distributed volume and connections ($\varepsilon_{VC/dist\_vol} + \varepsilon_{VC/connect} = 0.8834$), are not significantly different from 1. This suggests that as both the number of connections and the distributed volume increase, while the volume per connection remains stable, there are no additional cost benefits.

5.2.5. Estimating marginal cost and the shadow price of water

Accurately estimating the marginal cost (MC) of water production and distribution is essential for efficient resource allocation and sustainable pricing strategies. In network industries, cost efficiency is closely linked to economies of scale, and understanding these relationships is crucial for long-term financial sustainability.

Using the estimated cost elasticity $\varepsilon_{VC/dist\_vol}$, we calculate the marginal cost can be calculated with the standard formula: $MC = AC \times \varepsilon_{VC/dist\_vol}$, where AC is the average cost, calculated at the geometric mean of the explanatory variables used to estimate the translog cost function. In our sample, with a geometric mean of the distributed water volume of 374,353 m^3, we find $AC = 7.30$ DZD per cubic metre. Based on the estimated $\varepsilon_{VC/dist\_vol}$, we obtain a marginal cost $MC = 5.77$ DZD per cubic metre. These results confirm the existence of economies of scale in water distribution since $MC < AC$, implying that increasing water supply reduces the cost per cubic metre.

However, while the marginal cost accounts for direct production costs, it does not capture the opportunity cost of water as a scarce resource. As emphasised by Garcia and Reynaud (2004), an optimal pricing scheme that maximises the net social surplus should follow the social marginal cost rule:

$$P = MC + \lambda \tag{12}$$

where λ represents the shadow price of water in situ, or its the opportunity cost. This shadow price is strictly positive when water is scarce and/or when water withdrawals generate external, such as environmental degradation or depletion of groundwater reserves (Renzetti, 2002; Griffin, 2006).

To estimate λ, we propose to monetise the cost elasticity between total hours of water supply per week (hourweek) and production capacity (cap_prod). This elasticity provides a direct measure of marginal cost of providing an additional hour of service in terms of increased water abstraction costs. We assume that it is costly for water services to provide hours of service and production capacity together due to water scarcity. Indeed, when water is scarce, utilities must either ration supply or extract at higher marginal costs (e.g. from deeper aquifers or alternative sources). This acts as a shadow price of water, reflecting the opportunity cost of water use in the system.

This value is calculated from equation (11) at the sample mean. The average cost $\frac{VC}{y_i y_j}$ is calculated from the estimated constant of the translog cost function and the geometric mean of the variables hourweek and cap_prod, as:

$$\frac{VC}{y_i y_j} = \frac{\exp(14.821)}{125.78 \times 202.20} = 18.59 \text{ DZD per cubic meter}$$

This value is statistically significant at the 1% level, indicating a non-negligible opportunity cost for additional water extraction. In practical terms, this means that the economic value of water in situ is significantly higher than the production cost alone, reinforcing the need for pricing mechanisms that reflect scarcity and encourage conservation.

6. Discussion and conclusion

The objective of this study was to analyse the cost structure of Algerian water utilities using a translog cost function, with a particular focus on economies of scale, input substitution and the impact of water scarcity. By applying panel data techniques and instrumental variable methods, we accounted for unobserved heterogeneity and endogeneity concerns to obtain robust and unbiased estimates. Our results provide valuable insights into the efficiency of water production and distribution in Algeria and have several implications for water resource management, pricing policy and long-term sustainability.

These results have several important managerial and policy implications for improving the efficiency of water distribution systems. First, in terms of optimising production capacity, our results indicate that there are significant economies of scale in water production. This suggests that utilities could achieve cost reductions by consolidating or expanding production facilities to optimise capacity. Investing in larger, more efficient treatment plants would allow for lower variable costs per cubic metre of water produced, leading to improved financial sustainability.

The analysis also shows that there are significant economies of connection, meaning that connecting new customers without increasing the volume of water distributed can be achieved at a lower cost. Water utilities could prioritise household connections, particularly in areas where infrastructure already exists, to maximise the benefits of these new connections, spread fixed costs over a larger customer base and, most importantly, bring the last unconnected households onto the public service. Interestingly, our results suggest that increasing both the number of connections and the total volume of water distributed (economies of connection density), without optimising consumption per customer, does not necessarily lead to further cost reductions. This underlines the importance of demand management strategies such as pricing mechanisms or conservation programmes. Additional efficiency gains could be achieved by improving the distribution infrastructure. Reducing leakage, optimising pipe networks and implementing smart metering and leak detection systems would help reduce operating costs and improve service reliability.

The shadow price of water estimated in this study provides an important economic signal of resource scarcity and network constraints. When water is scarce, water utilities face difficult trade-offs: either rationing supply or withdrawing from more costly sources, such as deeper aquifers or desalination plants. A higher shadow price reflects the increasing economic burden of scarcity and emphasises the need for sustainable management practices.

Unlike conventional water pricing, the shadow price measure accounts for operational constraints, including the necessity of balancing service continuity (e.g., hours of supply) with physical water availability. This makes it a more accurate indicator for guiding infrastructure investments and regulatory decisions. If the shadow price is high, it signals the need for investments in alternative water sources such as desalination, wastewater reuse, or demand-side management measures such as conservation incentives and tariff adjustments. If the shadow price is low, this suggests that extending service hours does not place excessive stress on water resources, implying room for expansion without significant cost increases.

What are the implications for water pricing policy in Algeria? Our estimates indicate that the marginal cost of water supply (5.77 DZD/m^3) is close to the current base price for drinking water, excluding taxes, applicable in the studied wilayas (6.30 DZD/m^3, the price for the first "block" quantity of water in the context of increasing block tariffs). This suggests that existing pricing policies currently cover operating and maintenance costs. However, the shadow price of water (18.59 DZD/m^3) highlights the significant economic costs of scarcity that are not currently reflected in tariff structures. The high shadow price suggests that a pricing mechanism reflecting seasonal variations and scarcity levels could improve resource allocation.

Increasing Block Tariffs (IBTs), in which the volumetric price of water increases with blocks of water consumption, are practised in Tunisia, as in many other countries. This pricing structure is considered effective in encouraging conservation while maintaining affordability for essential consumption (Olmstead and Stavins, 2009). In practice, however, progressive pricing often fails to achieve equity. Differentiated tariffs and exemptions often create inequities between user groups (Wheeler et al., 2023). Targeted cash transfers or rebates to low-income households should be preferred to complex tariff schemes such as IBTs (Nauges and Whittington, 2017). Indeed, water utilities lack data on household size, and water consumption is weakly correlated with income. This results in wealthier small households being in the first (subsidised) blocks of consumption and benefiting from lower tariffs, while larger or low-income households (especially those sharing meters) face higher prices.

The significant economic burden of scarcity highlights the need for investment in desalination, wastewater reuse and leakage reduction as essential strategies to improve long-term sustainability. In particular, the observed trade-off between production and leakage suggests that addressing water losses should be a priority to reduce 'non-revenue water'. Investment in network maintenance and advanced metering technologies can help reduce waste and lower overall system costs.

This study provides a comprehensive analysis of the cost structure of Algerian water utilities, shedding light on economies of scale, network inefficiencies and the economic impact of water scarcity. Our findings highlight the need for strategic investments in production capacity and distribution efficiency, while underscoring the importance of pricing reforms to better reflect scarcity and ensure financial sustainability. By implementing these measures, Algeria's water utilities can move towards a more cost-effective and resilient water supply system, better equipped to meet the challenges of resource scarcity and growing demand.

Appendix

Table A1. Estimation results of control functions

	clhourweek			cldist_vol			clloss_rate		
VARIABLES	coef	tstat	pval	coef	tstat	pval	coef	tstat	pval
Instrumental variables									
Rainfall	0.047***	3.319	0.001	-0.014	-0.562	0.574	-0.018	-1.505	0.132
Rainfall_lag1	-0.001	-0.057	0.955	-0.093***	-2.876	0.004	-0.005	-0.313	0.754
Rainfall_lag2	-0.069	-1.596	0.115	-0.063***	-2.962	0.003	-0.027*	-1.712	0.087
Rainfall_lag3	0.043	1.478	0.144	-0.004	-0.117	0.907	-0.005	-0.322	0.748
Rainfall_lag4	-0.004	-0.091	0.928	0.064***	2.671	0.008	0.028	1.511	0.131
Temperature	0.711*	1.988	0.051	-0.266	-1.048	0.295	0.071	0.512	0.608
Temperature_lag1	-0.388	-1.492	0.141	-0.736***	-3.860	0.000	-0.081	-0.684	0.494
Temperature_lag2	-0.155	-0.636	0.527	-0.435***	-2.643	0.008	-0.342**	-2.194	0.028
Temperature_lag3	-0.123	-0.667	0.507	-0.430***	-3.999	0.000	-0.054	-0.599	0.549
Temperature_lag4	-0.783***	-2.662	0.010	0.032	0.145	0.885	-0.386***	-2.778	0.005
$(\text{Rainfall})^2$	0.037*	1.725	0.089	0.009	0.677	0.498	-0.011	-1.056	0.291
$(\text{Rainfall\_lag1})^2$	0.031	1.288	0.202	-0.073***	-3.529	0.000	-0.000	-0.039	0.969
$(\text{Rainfall\_lag2})^2$	-0.030	-0.901	0.371	-0.071***	-3.560	0.000	-0.013	-0.867	0.386
$(\text{Rainfall\_lag3})^2$	0.035	1.127	0.264	-0.009	-0.265	0.791	0.005	0.349	0.727
$(\text{Rainfall\_lag4})^2$	0.015	0.424	0.673	0.051**	2.040	0.041	0.023	1.185	0.236
$(\text{Temperature})^2$	1.190*	1.786	0.079	-1.053**	-2.012	0.044	0.599*	1.759	0.079
$(\text{Temperature\_lag1})^2$	-2.299**	-2.099	0.040	-1.018*	-1.660	0.097	-0.042	-0.133	0.894
$(\text{Temperature\_lag2})^2$	-1.306**	-2.149	0.035	1.233*	1.866	0.062	-0.536	-1.525	0.127
$(\text{Temperature\_lag3})^2$	0.816	1.187	0.240	0.387	0.785	0.432	0.205	0.656	0.512
$(\text{Temperature\_lag4})^2$	-1.664**	-2.249	0.028	-0.030	-0.040	0.968	-0.131	-0.338	0.735
pop_serv	-1.095	-1.110	0.271	-1.139**	-2.331	0.020	0.173	0.702	0.483
$(\text{pop\_serv})^2$	0.833	1.330	0.188	0.230	0.727	0.467	0.103	0.699	0.485
pop_serv_x_we	-0.053	-1.346	0.183	-0.008	-0.611	0.541	-0.014	-1.044	0.296
pop_serv_x_wl	0.016**	2.297	0.025	0.008**	2.575	0.010	0.000	0.083	0.934
pop_serv_x_length_supply	0.743	0.859	0.393	0.589***	3.555	0.000	0.069	0.583	0.560
pop_serv_x_length_dist	-1.111	-1.180	0.242	-0.907**	-2.570	0.010	-0.265*	-1.880	0.060
pop_serv_x_cap_prod	0.038	0.255	0.800	0.436**	2.548	0.011	-0.053	-0.908	0.364
pop_serv_x_cap_store	-0.233	-1.467	0.147	0.047	0.780	0.435	-0.044	-0.913	0.361
Exogenous cost variables									
connect	-0.007	-0.037	0.971	0.151**	2.176	0.030	-0.037	-0.447	0.655
hwe	0.277***	2.898	0.005	-0.117	-1.520	0.129	0.079*	1.869	0.062
hwl	-0.190***	-3.138	0.003	0.079	1.600	0.110	-0.048*	-1.832	0.067
length_supply				-0.621**	-2.173	0.030	0.133	0.699	0.485
length_dist	0.082	0.966	0.338	-0.002	-0.113	0.910	-0.028*	-1.830	0.067
cap_prod	0.130	1.045	0.300	0.568***	11.334	0.000	0.010	0.350	0.726
cap_store	-0.129*	-1.676	0.099	0.062**	2.210	0.027	-0.035	-1.300	0.194
connect2	-0.253	-1.128	0.263	0.273	1.320	0.187	0.109	0.994	0.320
$(\text{hwe})^2$	0.223***	3.098	0.003	-0.050	-1.039	0.299	0.033	1.208	0.227
$(\text{hwl})^2$	0.012***	2.945	0.004	0.003	1.602	0.109	0.000	0.092	0.927
$(\text{length\_supply})^2$	-0.082***	-2.996	0.004	0.005	1.057	0.291	0.006	1.016	0.310
$(\text{length\_dist})^2$	0.124	0.520	0.605	-0.046	-1.494	0.135	0.020	0.561	0.575
$(\text{cap\_prod})^2$	-0.081	-1.165	0.248	-0.144**	-2.056	0.040	0.058**	2.119	0.034
$(\text{cap\_store})^2$	-0.054	-0.847	0.400	0.027	1.395	0.163	-0.026	-1.213	0.225
we_x_wl	-0.097***	-3.163	0.002	0.021	1.016	0.310	-0.017	-1.354	0.176
connect_x_we	0.055	1.621	0.110	0.001	0.094	0.925	0.018	1.472	0.141
connect_x_wl	-0.014**	-2.010	0.049	-0.004	-1.423	0.155	-0.002	-0.558	0.577
connect_x_length_supply	0.152	1.003	0.319	-0.172***	-3.611	0.000	0.053	1.223	0.221
connect_x_length_dist	-0.047	-0.219	0.827	0.127*	1.692	0.091	-0.040	-0.691	0.489
connect_x_cap_prod	0.022	0.240	0.811	-0.186	-1.534	0.125	-0.034	-1.188	0.235
connect_x_cap_store	0.010	0.075	0.941	-0.147*	-1.943	0.052	0.024	0.432	0.666
length_supply_x_length_dist	-1.265*	-1.755	0.084	-0.025**	-2.389	0.017	0.036***	3.173	0.002
cap_prod_x_cap_store	0.129	1.542	0.128	0.089**	2.444	0.015	0.020	0.697	0.486
cap_prod_x_length_supply	0.015	0.166	0.869	-0.029	-0.857	0.391	-0.037**	-1.981	0.048

cap_prod_x_length_dist	-0.042	-0.400	0.691	0.050	0.536	0.592	0.001	0.035	0.972
cap_store_x_length_supply	-0.030	-0.455	0.650	0.061***	3.826	0.000	-0.008	-0.325	0.745
cap_store_x_length_dist	0.283*	1.883	0.064	-0.229***	-4.471	0.000	0.069*	1.817	0.069
t	0.061***	3.177	0.002	0.029***	2.855	0.004	-0.017*	-1.891	0.059
t^2	-0.002***	-2.849	0.006	-0.001*	-1.912	0.056	0.001*	1.869	0.062
Constant	-30.580	-1.109	0.271	-0.271***	-2.715	0.007	0.175***	2.657	0.008

Notes. Obs. = 1,320. Number of services = 66. T-stat and P-values are bootstrapped with the boottest package (Roodman et al., 2019) using the bootcluster() option to control the level of bootstrap clustering at the service and time dimensions.

References

Ali, E., Cramer, W., Carnicer, J., Georgopoulou, E., Hilmi, N.J.M., Le Cozannet, G., Lionello, P. 2022. Cross-Chapter Paper 4: Mediterranean Region. In: Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA, pp. 2233–2272.

Bouferrouk, A., Ouzzane, M., Dehmas, M. 2018. Leakage management in water distribution systems in Algeria: Challenges and solutions. Water Resources Management, 32(6), 1907-1921.

Brea-Solis, H., Perelman, S., Saal, D. 2017. Regulatory incentives to water losses reduction: the case of England and Wales. Journal of Productivity Analysis, 47(3), 259-276.

Chiappori, P.-A., de Palma, A, Picard, N. (2019). Couple residential location and ppouses workplaces. WP Elitisme 2018-02.

Christensen, L.R., Jorgenson, D.W., Lau, L.J. 1971. Conjugate duality and the transcendental logarithmic function. Econometrica, 39(3), 255–256.

Christensen, L.R., Jorgensen, D.W., Lau, L.J. 1973. Transcendatal logarithmic production frontiers. Review of Economics and Statistics, 55(1), 28-45.

Chambers, R.G. 1988. Applied production analysis: a dual approach; Cambridge University Press, Cambridge.

Destandau, F., Garcia, S. 2014. Service quality, scale economies and ownership: an econometric analysis of water supply costs. Journal of Regulatory Economics, 46, 152–182.

Filippini, M., Masiero, G., Santarossa, M. 2022. Productivity change and efficiency in the Swiss nursing home industry. Applied Economics, 54(25), 2837–2850.

Fuss, M., Waverman, L. 1981. Regulation and the multiproduct firm: The case of telecommunication in Canada. In: Fromm, G. (Ed.), Studies in Public Regulation. MIT Press, Cambridge, pp. 277–313.

Garcia, S. 2001. Economic analysis of water supply costs (Analyse économique des coûts d'alimentation en eau potable). Environnement et Société. Université des Sciences Sociales (Toulouse 1). Français. NNT: tel-02827779.

Garcia, S., Thomas, A. 2001. The structure of municipal water supply costs: Application to a panel of French local communities. Journal of productivity Analysis, 16, 5-29.

Garcia, S., Reynaud, A. 2004. Estimating the benefits of efficient water pricing in France. Resource and Energy Economics, 26(1), 1-25.

Griffin, R.C. 2006. Water resource economics: the analysis of scarcity, policies and projects. Cambridge, Mass.: MIT Press.

Khelladi, M. 2006. Water sector in Algeria: the reimbursable technical assistance programme (in French: Secteur de l'eau en Algérie : le programme d'assistance technique remboursable), p. 26-28, in: La Lettre d'information trimestrielle du Groupe de la Banque mondiale au Maghreb - Septembre 2006 - N°3

Krishnakumar, J. 2006. Time Invariant Variables and Panel Data Models: A Generalised Frisch Waugh Theorem and its Implications, Contributions to Economic Analysis, in: Panel Data Econometrics Theoretical Contributions and Empirical Applications, pages 119-132, Emerald Group Publishing Limited.

Mardones, C., Orellana, A. 2023. Estimation of a demand system to obtain the price elasticities of water and elasticities of substitution in the Chilean industrial sector. Water Resources and Economics, 44, 100234.

Maziotis, A., Molinos-Senante, M. 2022. Economies of integration and sources of change in productivity in the Chilean water and sewerage industry: a translog cost function approach. Environmental Science and Pollution Research, 29:8503–8513.

MedECC 2020. Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report.

Molinos-Senante, M., Mocholí-Arce, M., Sala-Garrido, R. 2016. Estimating the environmental and resource costs of leakage in water distribution systems: A shadow price approach. Science of The Total Environment, 568, 180-188.

Molinos-Senante, M, Maziotis, A., Ramón Sala-Garrido, R., Mocholi-Arce, M. 2022. Estimating performance and savings of water leakages and unplanned water supply interruptions in drinking water providers. Resource, Conservation and Recycling, 186, 106538.

Nauges, C., Whittington, D. 2017. Evaluating the performance of alternative municipal water tariff designs: Quantifying the trade-offs between equity, economic efficiency, and cost recovery", World Development, 91, 125–143.

Olmstead, S.M., Stavins, R.N. 2009. Comparing Price and Nonprice Approaches to Urban Water Conservation. Water Resources Research, 45: 10.

SOGREAH/ICEA 2002. National Study on the Pricing of Water for Domestic and Industrial Use (Part 1) (Étude nationale sur la tarification de l'eau à usage domestique et industriel, in French). Ministry of Water Resources, Algeria, 97 p.

Ministry of Water Resources 2017. (Ministère des Ressources en Eau). Alger.

Mundlak, Y. 1978. On the Pooling of Time Series and Cross Section Data. Econometrica, 46(1), 69-85.

Panzar, J.C. 1989. Technological Determinants of Firm and Industry Structure, Ch. 1 in Handbook of Industrial Organization (R. Schmalensee and RD Willig, Eds.). Elsevier.

Renzetti, S. 2002. The Economics of Water Demands. Norwell, Mass.: Kluwer Academic Press.

Roberts, M.J. 1986. Economies of Density and Size in the Production and Delivery of Electric Power. Land Economics 62(4), 378–387.

Roodman, D., Nielsen, M.Ø., MacKinnon, J.G., Webb, M.D. 2019. Fast and wild: Bootstrap inference in Stata using boottest. The Stata Journal, 19(1), 4-60.

Torres, M., Morrison Paul, C.J. 2006. Driving Forces for Consolidation or Fragmentation of the U.S. Water Utility Industry: A Cost Function Approach with Endogenous Output. Journal of Urban Economics, 59(1), 104–120.

Wheeler, S.A., Nauges, C., Grafton, R.Q. 2023. Water pricing, costs and markets: Technical Report for the Global Commission on the Economics of Water. OECD Environment Directorate Climate, Biodiversity and Water Division. https://watercommission.org/publication/water-pricing-costs-and-markets/

White, H. 1980. Using Least Squares to Approximate Unknown Regression Functions. International Economic Review, 21(1), 149-70.

Whittington, D., Nauges, C. 2020. An assessment of the widespread use of increasing block tariffs in the municipal water supply sector. In Oxford Research Encyclopedia of Global Public Health. Oxford University Press.

Wooldridge, J.M. 2010. Econometric Analysis of Cross Section and Panel Data. MIT press.

World Bank 2021. Water in the Balance: The Economic Impacts of Climate Change and Water Scarcity in the Middle East and North Africa.

Xiao, C.C., Makarchev, N., Tao, X. 2024. Scales and size-quality outcomes in adult learning disability residential care: evidence from the UK. The European Journal of Health Economics, 25, 655–669.

Zeggagh, A. 2012. Pricing of drinking water services, sustainability of the resource and user access: the case of Algeria (Tarification des services d’eau potable, durabilité de la ressource et accès des usagers: Cas de l’Algérie. In French). Thèse de Doctorat, Université d’Alger 3.

Zeggagh, A. 2020. Pricing and domestic use of Algerian water services: A micro-econometric approach (Tarification et usage domestique des services d’eau algériens : Approche micro-économétrique. In French). Les Cahiers du Cread, 36(2), 85-117

Zeggagh, A., Thomas, A., Ferfera, M.Y. 2010. Economic evaluation of the performance of Algerian drinking water utilities (Evaluation économique des performances des services d’eau potable algériens. In French). Les Cahiers du CREAD, N°92, p. 119-152.

Zeggagh, A., Mazouz, K. 2024. Modeling the Water Supply Costs of the Algerian Municipalities. Water Conservation Science and Engineering, 9, 82 (2024).