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The generalised translog cost function to estimate tariffs for potable water: The case of Tunisia

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Abstract

The present study aims to estimate the marginal cost of potable water supply and analyse the implications for more efficient, equitable and income-adequate tap water tariffs in Tunisia. Furthermore, this article aims to develop a new pricing model for potable water. Pricing by the Tunisian water utility focuses on setting water prices to cover average costs, often using designs that increase clogging rates. This results in a large volume of potable water being wasted. To facilitate the efficient estimation of pricing models, we attempt to introduce generalised translog (GT) cost specifications for multiple products including Box-Cox transformations. It turns out that the marginal social cost of providing a cubic meter of water must consist of two components: volumetric charges, at €0.048/m^3, and connection water charges, of €0.055/km.

Key words: generalised translog specification, Box-Cox transformation, marginal social cost, potable water, Tunisia

1. Introduction

In some countries, the public interest is focused mainly on technological solutions to water scarcity (Sibly 2006b). For economists, however, pricing is an important mechanism for determining the efficient allocation of water resources (Zhu & Van Ierland 2012). Pricing ensures that the available water is used for its most valuable uses, and new supplies are developed only if consumers are willing to pay (Pint 1999). Water scarcity can be addressed if water is managed properly as an economic commodity (Dinar & Nigatu 2013). To achieve this, the total cost of the water supply must be considered. Rogers *et al*. (1998) argue that sustainable and efficient water use requires water prices to cover all costs: operation, maintenance, capital and opportunity cost (Sibly 2006a). Ignoring operation costs can underestimate the value of water and lead to the misallocation of resources (Rogers *et al*. 1998). The resource is utilised most valuably when the water allocation reflects its full cost (Rogers *et al*. 2002). Municipal water utilities have traditionally set water prices to cover the average cost (Pint 1999). Griffin (2006), however, argues that average cost price is not a good efficiency booster. Effective pricing is synonymous with marginal cost pricing. Furthermore, the average cost price system used by municipal water utilities does not take into account the scarcity value of natural water (Pint 1999).

Tunisia is one of the countries in which efficient water pricing has received little attention. The Tunisian Water and Distribution Utility (TWDU) addresses the country's chronic water shortage by increasing water supplies and fixing water prices to reach the average cost. Furthermore, Tunisia does not value natural (raw) water: the TWDU does not pay for the raw water it uses to supply its customers with tap water. Therefore, the price it charges for tap water only takes into account the average cost of water collection, treatment, storage and distribution, and not the scarcity value of the resource itself (Gezahegn & Zhu 2017). In addition, the TWDU appears to be following flawed accounting practices that may understate its cost of capital: since 2000, for example, no interest and no depreciation have been shown. The cost of handling materials was also ignored. It is entirely possible that the reduced cost translates into a lower average cost, which would ultimately lead to the undervaluation of tap water, not to mention the inherent inconsistency of the average cost price with economic efficiency. In addition to economic efficiency, the criteria for designing water charges should also consider income efficiency and equity, since water is an economic and social good (Hall *et al*. 2009). Marginal cost pricing may not address efficiency, equity and income adequacy simultaneously (Sibly 2006a). Since the TWDU is a natural monopoly, average cost decreases as output increases, implying that the marginal cost is lower than the average cost (Gezahegn & Zhu 2017). As a result, the marginal cost price scheme leads to revenue deficiency (Sibly 2006b).

It is important to note that tariffs and subsidies are not the only solution to improve access to potable water in developing countries. It is also important to improve the infrastructure and management of the water systems to ensure a sustainable supply of safe water for drinking. In many developing countries, tariffs for potable water are typically low and often do not reflect the true cost of providing the service. For example, the average tariff for domestic households in India is around $0.25 per month, while the cost of providing the service is estimated to be around $0.50 per month. This can result in inadequate funding for maintenance and the expansion of the water supply system, leading to poor service quality and limited access to safe water for drinking (Singh *et al*. 2005). In the city of Kampala, Uganda, the tariff is based on a tiered pricing structure, where the more water a customer uses, the higher the price they pay per unit of water. For example, customers who use less than 20 000 litres of water per month pay a lower rate per litre than customers who use more than 20 000 litres per month. There also is a fixed monthly charge that is applied to cover the cost of maintaining the water supply infrastructure (Nsubuga 2014).

In Tunisia, water is priced on the basis of an increasing block rate (IBR) structure (Figure 1). However, Gezahegn and Zhu (2017) present several disadvantages of IBR. First, IBR pricing has the effect of insulating ordinary consumers from facing the cost of decreased water availability. Second, in terms of IBR pricing, large but low-income families are likely to face a higher price compared to small but high-income households. Third, it sends the wrong price signals not only to consumers, but also to the TWDU.

Therefore, the marginal cost estimated in this paper serves only as the lower bound of the true marginal cost of the Tunisian water supply. The term marginal social cost (MSC) is used to describe the marginal cost of water supply based on the marginal value of potable water.[1] What we are advocating is a long-term marginal cost (LRMC), which is the incremental cost per unit of water when all factors of production (including capital) change gradually (Gezahegn & Zhu 2017). The capacity expansion of water supply networks has been sporadic rather than gradual (Sibly 2006a). Turvey (1976) distinguishes between distribution networks and centralised systems. The former can scale with many small investments, while the latter often requires large investments over a long period of time. Therefore, it may make sense for Tunisia to consider the distribution network as an incremental variable, since the expansion of the distribution network is mainly to satisfy growing

[1] Marginal value is the value to a consumer of the last unit of consumption

demand, rather than being an investment. Satisfied with the central region system, LRMC prices outperform short-run marginal cost prices in the water sector and provide stable capital for long-term investments (London Economics 1997). Because an LRMC-based rate is stable (Sibly 2006b), the LRMC approach has lower administrative costs than the more dynamic, short-term marginal cost approach (Garcia & Reynaud 2004).

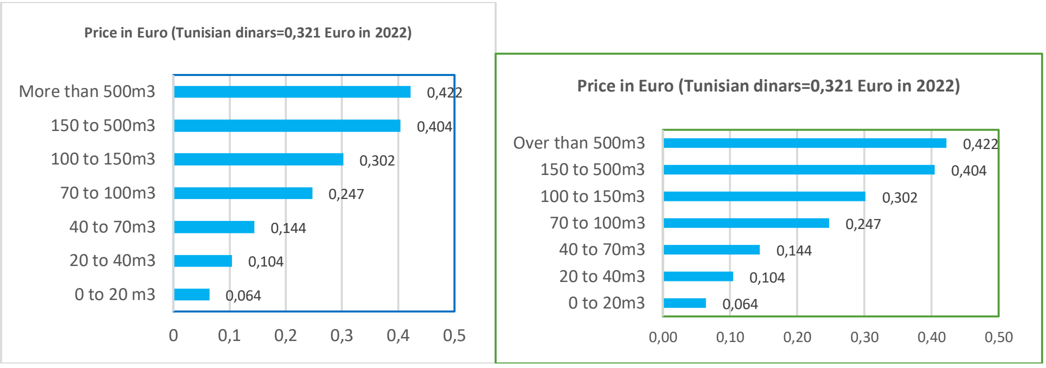

Figure 1: Increasing block rate used by Tunisian water utility
Source: SONEDE[2] (2019)

We applied the Box-Cox cost specification to two products (supply and pipeline connection) that take into account the operational cost of potable water in the context of a developing country. However, an important question arises regarding the specification of the functional form of the estimated cost function. Interestingly, experimental applications have focused on a single ad hoc functional specification, primarily translog and Cobb-Douglas. However, choosing the right functional form is not an easy task. It is well known that functional forms are ‘data’ and ‘model’ specific, and differ in their convergence properties and ability to approximate alternative technologies. Simply put, there is no single form of function in all cases – the appropriate functional specification is case specific. If the empirical estimates are biased by imposing an inappropriate functional form, the predictive responses obtained from the model may be biased and inaccurate, posing serious design problems for policy, and/or policy implications. Thus, when there is no strong a priori theoretical or experimental reason to support a particular functional specification, exploring the sensitivity of what would be economically optimal, and its effect, on the choice of the functional form becomes important.

The purpose of this study was to estimate the marginal cost of water supply and analyse the implications for more efficient, equitable, and revenue-sufficient system based on a full economic cost approach. To estimate the cost function, we used the Box-Cox transformation. Here, we do not claim any methodological innovation, but the inclusion of the value of tap water in the ‘appropriate’ cost specification is a novel contribution to the empirical literature on water pricing in Tunisia.

The remaining part of the paper proceeds as follows: Section 2 presents a brief description of the study area; Section 3 outlines the methodological approaches and model specification followed; Section 4 presents and discusses the results; while Section 5 concludes.

2. The study area

The dataset used in this study consists of an unbalanced panel from the TWDU covering 11 years and 21 district management utilities (DMU). In the empirical application, we focused only on the water service and did not consider sewerage. The descriptive statistics of the variables included in the model are presented in Table 1. The total distribution cost ($\boldsymbol{C}$) is equal to the operating and capital

[2] SONEDE is the Société Nationale d’Exploitation et de Distribution des Eaux, the Tunisian water distribution utility.

expenditure. The price of the material (***P****M*) is obtained by dividing the material cost by the length of the distribution network in kilometres. The material cost consists of various groups of costs obtained when subtracting capital and labour costs from the district's total cost. The price of capital (***P****K*) is calculated as the ratio of capital cost and capital stock, which is approximated by the capacity of pumps measured in litres per second. The capital cost consists of depreciation and interest, where depreciation accounts for most of the capital cost. The price of labour (***P****L*) is equal to the average annual wages, estimated as labour expenditure divided by the average number of employees for a given year. The price of energy (***P****e*) is equal to the energy cost divided by the amount of water supplied.

The first output (q_w) is measured as the amount of water supplied to the final customers expressed in cubic metres. The second output (q_{AS}) is the size of the service area expressed in kilometres (connection).

Table 1: Descriptive statistics (Tunisian dinars (TD) = 0.321 Euro in 2022)

Variable description	Variable	Mean	Std dev.	Minimum	Maximum
Total annual cost (TD)	C	5 990 438	4 490 933	135738	2.34e + 07
Price of labour (TD)	L	10 189.06	7 254.575	550	81 683
Price of capital (TD)	K	207.75	163.9824	10	2 375
Price of water (TD)	M	92.096	90.683	9.271	106.784
Price of energy (TD)	E	34 924.9	28 564.01	566	300 075
Water supplied (m^3)	Q	10 885.62	8 400.726	2426	34 678
Size of service area (km)	AS	54.25	15.48593	22	100

Note: TD = Tunisian dinar, which was equal to 0.321 Euro in 2022

3. Model specification

Martins *et al*. (2012) propose a cost function with two outputs: water loss and service output. Garcia and Thomas (2001) define the water industry as a multi-product firm producing two outputs: losses and the actual water produced. Kim (1995) identifies US water utilities as multi-product firms providing residential and non-residential services. Hayes (1987) views the cost structure of the water industry in the US as being similar to that of a multi-product firm producing wholesale retail products. Following the lines of argument in favour of the multi-product approach, the present study treats the TWDU as a two-output firm producing connection (q_{AS}) and distribution (q_w) water outputs. A time variable, t, was included in the model to account for a Hicks-neutral technical change, as in Ray (1982). Besides q_w, q_{AS} and t, the multi-product cost function includes the prices of capital (p_k), labour (p_l), energy (p_e) and material (p_M) as its arguments. That is, C = C(q_w, q_{AS}, p_k, p_l, p_e, p_M, t) implicitly.

According to the well-known generalised translog (GT) specification, the cost function is given by Caves *et al*. (1980) as:

$$\ln C = \alpha_0 + \sum_i \alpha_i q_i^{(\pi)} + \frac{1}{2}\sum_i \sum_j \alpha_{ij} q_i^{(\pi)} q_j^{(\pi)} + \sum_i \sum_k \alpha_{ik} q_i^{(\pi)} \ln p_k + \sum_k \alpha_k \ln p_k + \frac{1}{2}\sum_k \sum_l \alpha_{kl} \ln p_k \ln p_l + \alpha_t t + \varepsilon, \quad (1)$$

where C is the cost of production, q_i refers to outputs (water distribution and connection), p_k indicates factor prices, and the superscripts in parentheses, (π), represent the Box-Cox transformations of the outputs:

$$q^{(\pi)} = (q^{\pi} - 1)/\pi \text{ for } \pi \neq 0 \text{ and } q^{(\pi)} \longrightarrow \ln(q) \text{ for } \pi \longrightarrow 0.$$

The associated input cost-share equations are obtained by applying Shephard's lemma to the expression in Equation (1):

$$S_k = \partial \ln C / \partial \ln p_k = \sum_i \alpha_{ik} q_i^{(\pi)} + \alpha_k + \sum_l \alpha_{kl} \ln p_l + \varepsilon \quad (2)$$

Setting $\pi \rightarrow 0$ in Equation (1) and Equation (2) yields the standard translog (ST) specification, with all output terms in the cost function and the corresponding cost-share equations assuming the usual logarithmic form. For small values, the estimated generalised translog function is an approximation in the form of the ST function. Because of its log-additive output structure, ST suffers from the well-known failure to assess cost behaviour when any output is zero. This has been shown to lead to inappropriate and/or highly volatile estimates of economies of scope and product-specific economies of scale (Bottasso *et al*. 2011).

An estimate of the marginal social cost of output i (MSCi) is computed as follows:

$$MSC_i = \partial C / \partial q_i = \left(\partial \ln C / \partial q_i \right). C = (\alpha_i q_i^{\pi-1} + \sum_j \alpha_{ij} q_j^{(\pi)} q_i^{\pi-1} + \sum_k \alpha_{ik} q_i^{\pi-1} \ln p_k). C, \quad (3)$$

where $\hat{C}$ = the fitted value of the cost function (Equation (1)) as in Kim (1995), and $\xi_i = \partial \ln C / \partial \ln q_i$ is the elasticity of cost for output i. The economies of scale (ES) are also measured as follows (Coelli *et al*. 2005):

$$ES = [\sum_{\xi_i}]^{-1} \quad (4)$$

The TWDU would face increasing, constant or decreasing returns to scale if economies of scale are greater than, equal to or less than one.

4. Estimation and empirical results

Data on costs, output quantities and input prices were obtained by integrating the information available in the annual reports and cost accounting of the TWDU. All coefficients of the multi-product cost function (Equation (1)) were computed mutually with their associated input cost share (Equation (2)). To stave off the singularity of the covariance matrix, the capital share equation (S_k) was deleted, and only the labour (S_l), energy (S_e) and material (S_M) share equations were included in the systems. Before the estimation, all variables were standardised on their respective sample means, and estimates were obtained via a non-linear generalised least squares estimation (NLSUR), which is the non-linear counterpart of Zellner's iterated and seemingly unrelated regression technique to ensure that the estimated coefficients are invariant concerning the omitted share equation (Zellner 1962). Our NLSUR estimation was carried out in R using the system fit package (Henningsen & Hamann 2007). Assuming the error terms in the above models are normally distributed, the estimation of different parameter and log-likelihood ratios for the estimated cost function and the related labour, energy and material share equations respectively can be computed.

The summarised results of the NLSUR estimates of the generalised translog cost (GT) specification and its share equation are presented in Table 2. In the first row, the value of the Box-Cox parameter (π) for the GT specification is positive (0.0787) and significantly different from zero (p-value = 0.027). Smaller values indicate that the GT model is very close to the standard or simple translog form (ST), as it suffers from the same drawbacks as the ST specification when used to estimate firm cost characteristics for multiple products.

Table 2: NLSUR estimation of the generalised translog

Variable	Parameter	Estimate	Student's t-test	Variable	Parameter	Estimate	Student's t-test
Box-Cox parameters	π	0.078	2.878	q_w*lnp_m	α_{ASM}	0.023	1.15
Constant	α_0	1.775	2.536	lnp_k*lnp_k	α_{kk}	0.094	4.7
q_w	α_w	0.184	2.115	lnp_k *lnp_l	α_{lk}	-0.079	-2.633
q_{as}	α_{AS}	0.187	1.069	lnp_k*lnp_e	α_{ke}	-0.049	-2.45
lnp_k	α_k	0.382	34.727	lnp_k*lnp_m	α_{kM}	-0.048	-4
lnp_l	α_l	0.173	7.864	lnp_l*lnp_l	α_{ll}	0.051	7.286
lnp_e	α_e	0.228	10.364	lnp_l*lnp_e	α_{le}	0.008	1.143
lnp_m	α_M	0.22	8.8	lnp_l*lnp_M	α_{lM}	-0.047	-5.222
q_w*q_w	α_{ww}	0.087	2.719	lnp_e *lnp_e	α_{ee}	0.039	7.8
qw*qas	α_{rw}	0.254	4.618	lnp_e *lnp_m	α_{eM}	-0.018	-2.571
q_{as}*q_{as}	α_{rr}	0.377	1.551	lnp_m*lnp_m	α_{ww}	0.053	3.533
q_w*lnp_k	α_{wk}	0.037	2.643	t	α_t	0.004	4
q_w*lnp_l	α_{wl}	-0.001	-0.091	R^2 cost function		0.98	
q_w*lnp_e	α_{we}	-0.018	-2.571	R^2 labour share equation		0.95	
q_w*lnp_m	α_{wM}	-0.018	-2	R^2 energy share equation		0.94	
q_w*lnp_k	α_{ASk}	-0.042	-1.313	R^2 water share equation		0.92	
q_w*lnp_l	α_{ASl}	0.034	1.36	VIF (mean)		1.89	
q_w*lnp_e	α_{ASe}	-0.011	-0.55	Log-likelihood		-194	

The R^2 for the cost function and the cost-share equations is very similar. McElroy's (1977) R^2 ($R^2{}_*$) can be used as a measure of the goodness of fit for the NLSUR system. The model (Table 2) appears to fit the data well and explains more than 95% (R^2) of the variation in the dependent variable. q_w and q_{AS}, which are all input prices, are shown to be positive and important parameters, as one would normally expect: the cost of water supply increases with output and input price levels, ceteris paribus. However, the parameter of q_w has a positive sign, which does not seem surprising. Note, however, that water supply costs also include costs associated with avoiding water loss that may occur if leaks are not repaired. Water distribution requires network maintenance costs, leading to higher overall water supply costs, as waste is offset by more expensive production.

The positive and significant parameter of the interaction between q_w and q_{AS} (α_{wAS}) implies that an increase in q_w would necessitate an increase in the marginal cost of q_{AS}. Yet this implies that the marginal cost of q_{AS} would depend on the level of q_w. These results combined imply that there would be cost advantages to producing q_{AS} and q_w jointly in Tunisia.

At last, it is cheaper to fix the leak (to meet demand) than to pump more water in Tunisia. This result suggests that there are incentives to reduce urban water loss and supports concerns that the available water should be used cautiously. Reducing water loss has economic and financial implications, among other things. From an economic point of view, it alleviates water scarcity; and financially, it avoids the potential loss of revenue affecting water prices. As Cousin and Taugourdeau (2015) point out, if water loss occurs, the TWDU can charge consumers higher fees to compensate for waste, resulting in a deadweight loss. The parameter t is positive and significant, indicating that, for a fixed level and entry price, costs increase over time. This could be one possible explanation for the rising cost of water supply over time.

The MSCs were calculated based on Equation (3). Note that, because of the inclusion of the price, rather than the stock, of capital in the cost function, the estimated marginal cost is the long-term marginal cost. This implies that not only expenditure on variable inputs, but also expenditure on network expansion, is accounted for, as noted by Renzetti (1992). The positive sign (Table 3) of the marginal social cost of q_w indicates an increase of €0.048 in the cost of water supply if one cubic metre of water is produced. Similarly, an additional metre of network connection generates an additional cost of about €0.055 per km for each TWDU subscriber.

To understand to what extent water is under-priced in Tunisia, we calculated increasing block rate (IBR) prices, $\widetilde{p}$, as $\widetilde{p} = \sum_i w_i p_i$, where p_i is the average price in block i (Figure 1) and w_i is the share of the total water consumed in block i, and compared it with the estimated marginal social cost. The difference between $\widetilde{p}$ and MSC for q_w was negative, suggesting that the current IBR pricing in Tunisia leads to a considerable difference between what it costs society to supply an additional cubic metre of water and the price actually paid by consumers (q_w is priced at a rate of 21% below the MSC).

Table 3: Estimation of marginal social cost (MSC) and economies of scale (ES)

	Water demand: q_w	**Connection: q_{AS}**
MSC	€0.048/m^3	€0.055/km
elasticity ξ_i	0.31	0.45
ES	1.316	

The degree of ES has a value of 1.316 (Table 3). This value means that a 10% increase in all inputs gives rise to a 13.16% (more than proportionate) increase in aggregate water output. This indicates the conformity of the TWDU with the natural monopoly nature of water utilities. It furthermore indicates a higher average cost than the marginal cost of water supply in Tunisia and has implications for cost recovery if water prices are set at a rate equal to the estimated MSC: revenues will be lower than costs, leading to a deficit.

Apart from the inherent problems of IBR pricing, the revealed under-pricing effect of IBRs in Tunisia calls for a more appropriate pricing scheme. Furthermore, since IBRs are inflexible, their application stands against economic efficiency on account of the inconsistent nature of water availability in the cities, where water variability is rampant. Failure to cover the cost of water provision is another problem, since $\bar{p}$ is lower than MSC.

On average, Tunisia suffers a revenue deficit of approximately MSC – $\bar{p}$ in supplying q_{AS} and q_w. Although marginal cost pricing is superior to the IBR pricing on efficiency grounds, MSC pricing will not address the revenue sufficiency criterion, and since the MSC (for a given level of output) is a fixed value, poor and rich households will face the same water price, disregarding equity. Given the under-pricing and revenue non-sufficiency effects in Tunisia, we recommend a two-part tariff, consisting of a volumetric charge and a connection charge to serve the efficiency and revenue sufficiency goals simultaneously. This is needed to cover the total costs (Sibly 2006a). Since it is independent of the volume consumed, the connection charge is a load related to the connection to the TWDU network. It is not influenced by the consumers' choice of volume, but rather by the distance between the consumer and the power plant at the TWDU. Thus, a proposal for Tunisia would be to set volumetric charges of €0.048/m^3 and €0.055/km for q_w and q_{AS} respectively. The implication of this is that water prices would be 3.2 times higher than the current ones.

5. Conclusions

We empirically estimated the marginal social costs MSCs of water supply in Tunisia using a generalised translog cost function specification. In particular, we included the value of natural water in the cost function to capture the opportunity cost of urban water. This is a new contribution to the water-pricing literature, especially for regions where natural water is taken for granted and no value is assigned to it. Our results show that increasing block rate (IBR) prices in Tunisia are lower than the estimated marginal social cost of the TWDU. Water supply (q_w) is priced more inefficiently than its MSCs. As mentioned in Section 1, our analysis excludes externalities related to urban water supply. Therefore, the IBR prices are much lower than genuine MSCs, which is a necessary condition for increasing water prices in Tunisia. Not only is inefficiency, but also the insufficient recovery of water supply costs, a problem: the TWDU has a revenue deficit in water supply.

The MSC pricing furthermore is inappropriate because it does not address revenue adequacy and equity issues. To fill the gap between MSC pricing and total cost revenues, Tunisia proposed a two-part tariff: setting a volume fee of €0.048/m^3 for q_w and a connection fee of €0.055/km for q_{AS}, which seem to be the lower layers of the technology considered to serve the purposes of efficiency and yield safety. Furthermore, there also is a fixed charge, which is a monthly or quarterly charge that is applied to cover the cost of maintaining the water supply infrastructure, such as the cost of building and maintaining treatment plants, reservoirs and distribution networks. This charge depends on the emplacement of the water consumption meter (measured in €/km: connection marginal cost). A volumetric charge is a charge that is based on the amount of water a customer uses, typically measured in €/cubic metres. The volumetric charge is usually tiered, meaning that customers who use more water will pay a higher price per unit than customers who use less water. This type of pricing structure is intended to encourage the conservation of water resources and can also help to cover the cost of providing services to customers in more remote areas.

Issues of equity would also be addressed, either by charging different connection fees for different groups of consumers, or by subsidising the connection fees for low-income consumers after they have paid for the water supply. The introduction of MSC-based flexible volume rates will require additional costs.

However, since the estimated marginal cost is a long-term marginal cost, it may not be flexible enough and its costs may outweigh the benefits of introducing a more efficient, fair and adequate water price, which illustrates how effectively water should be priced in the study area. Fixing water prices at the estimated MSC has two positive effects. First, higher prices are said to incentivise households to conserve water, which will lead to better use efficiency, assuming people become more cautious about using water as prices rise. Second, charging higher prices will partially help the TWDU recoup its utility costs. Therefore, it is necessary to increase the price of the MSC for water supply in order to send the correct signal to water users about the social costs of a unit increase in their demand.

When water prices are lower than the social utility costs, users do not view water as an economic resource. When the price is increased to the estimated marginal social cost, users will gain a better understanding of the cost of meeting their water needs and have a greater incentive to use water more prudently. Although our analysis in this paper focuses on water pricing in Tunisia, the approach can be applied to many cities in developing countries, where water pricing does not meet the conditions of efficiency and earning sufficient income.

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