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A long-run analysis of residential water consumption

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Abstract

The main originality of this paper is to empirically investigate the long-run relationship between average regional water consumption and its determinants. To do so, we use quarterly non-stationary panel data covering the six Tunisian regions for the period 1980.1 to 2007.4 and a breakdown into two consumption blocks (a lower and an upper block). We apply the panel cointegration tests and estimation developed by Pedroni (1999). We obtain a long-run price elasticity for the upper block that is greater than the corresponding one for the lower block. Our results show that water tariffs can play an active role in conserving the precious water resource in countries characterized by scarcity, volatility and low water quality as is the case with Tunisia.

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1. Introduction

Tunisian water resources are characterized by acute scarcity, quality problems, bad distribution as well as time and space volatility. Tunisia, like all other similar countries, is thus obliged to manage this very limited resource to meet actual population needs, boost its fragile economy and, above all, to preserve this strategic resource for future generations.

Even though residential water demand is limited, compared to irrigation demand which monopolizes more than 80 % of total resources, it must be carefully managed for at least two reasons: firstly, this component must be satisfied only by water of good quality (softness, purity etc.). Secondly, residential water requires a minimum of regularity, security and reliability especially during the dry season. These constraints are difficult to satisfy in a country where variability in rainfall is frequent. Thirdly, residential water consumption is exponentially increasing as a result of the rapid urban and economic development of an emerging country like Tunisia, where all activities require a larger quantity of water with acceptable quality available in the right time and place.

Thus, as Tunisia, as well as all the other similar countries, wants to avoid, or at least to postpone, the mobilization of non-conventional water (desalinization, virtual water, etc.) with significantly higher costs, the only alternative is to rely on appropriate water demand management. Water pricing must be considered seriously as a useful tool, along with the other non-price instruments, such as awareness, education, water conservation and participatory management, to keep the evolution of demand under control.

Residential water demand has been a major issue in environmental economics as proved by the number of recent surveys available in the literature (Arbuès et al (2003), Dalhuisen et al (2003), Worthington and Hoffman (2008)). Most of this research has been conducted in developed countries, but some studies also exist for developing countries, (see Nauges and Whittington, 2010).

Nauges and Thomas (2003) have estimated a dynamic panel data model on a sample of French municipalities and have obtained short and long-run price elasticities respectively equal to -0.26 and -0.40. Using times series observations from Seville in Spain, Martinez-Espineira (2007) has derived the long-run price elasticity equal to -0.5 from a cointegration model and the short-run price elasticity equal to -0.1 from an error correction specification. The use of the panel cointegration technique allows as estimation of the Tunisian residential water demand model in a heterogeneous cointegrated panel of six regions.

The Tunisian water utility, SONEDE (the national water exploitation and distribution company), uses non-linear pricing based on five categories (see comment below). So the first step will be to design the right decomposition. We will show that the best choice is to build a two- block tariff (a lower and an upper block). The main objective of this research is to give more policy recommendations to the Tunisian water utility using an original database and a recent econometric technique.

In this paper, we propose an original analysis of residential water demand in Tunisia using panel cointegration techniques. To the best of our knowledge, no other studies have integrated the non-stationary feature of data to analyze water demand determinants. Section 2 will describe our database and present the model. The new econometric technique, which has been extensively developed during the last period and on which we will rely, is briefly surveyed in section 3. The empirical investigation, as well as the comments and the analysis of the main results form section 4. Finally, the policy recommendations will form the conclusion.

2. Model and Data

2.1. The Model

The conventional water demand model is often defined in the literature (see Arbues and al, 2003) as an equation in double log form. The latter links household water demand to its determinants such as price and income, as the main determinants of demand suggested by classical economic theory, followed by socio-economic factors and climatic factors (temperature and rainfall) as the control variables. In this study, the demand model is specified at regional level for each consumption block. Thus, for a period *t* (quarter) and individual *i* (region), the demand equation is specified as:

$$LnC_{it} = \alpha_0 + \alpha_1\, LnP_{it} + \alpha_2\, LnI_{it} + \alpha_3\, LnRL_{it} + \alpha_4\, LnNE_{it} + \boldsymbol{\varepsilon_{it}} \qquad \textbf{(1)}$$

Where C, P, I, RL and NE denote average quarterly water consumption, average water price (the total bill divided by the volume consumed), average household income, rainfall and network expansion (quarterly share of subscribers in the lower or upper blocks) respectively. $\boldsymbol{\varepsilon_{it}}$ is a zero mean error term normally distributed and *Ln* denotes the logarithmic operator used to linearize the equation and then we interpret the coefficient as elasticity.

2.2. Data description

The data have been collected by SONEDE, since 1980, by bracket of consumption, quarter and district. So the data base used by this work will cover the period beginning from 1980 and going to 2007. SONEDE provides data on household consumption into 13 brackets. We will aggregate these into 5 brackets corresponding to those used for the 5 different tariff rates:
- Bracket 1: 0-20 m^3 per connected household, per quarter,
- Bracket 2: 21-40 m^3 per connected household, per quarter,
- Bracket 3: 41-70 m^3 per connected household, per quarter,
- Bracket 4: 71-150 m^3 per connected household, per quarter, and
- Bracket 5: more than 150 m^3 per connected household, per quarter.

Data on income, derived from budget surveys compiled by the national statistical institute in Tunisia, has also been collected. Next, data on average quarterly levels of rainfall (ml/quarter) in each region are collected by the national institute of meteorology.
Our sample will then be composed of 112 quarterly observations in six regions, namely; Great Tunis (GT), which includes Tunis with its suburbs, North East Tunisia **(NE)**, North West Tunisia (NW), Central East Tunisia (CE), Central West Tunisia (CW) and Southern Tunisia (S).

The analysis of the figures (1) and (2) clearly reveals a stabilization of the consumption during the past decades which indicates a structural change that we will detect analytically later. After careful observation of the aforementioned figures, we will intuitively try, before confirmation by objective analysis, to explain consumer behavior in the long-run. Indeed, the smooth decrease of average consumption in the 5th and the 4th brackets is certainly the result of water tariffs which have seen a rapid increase during the past years and perhaps of the use of alternative resources such as pumping directly from the shallow aquifer. However, the stability of the lower brackets (the first three brackets) is certainly due to the inelasticity of the water consumption for those low income households which are just satisfying just the basic needs.

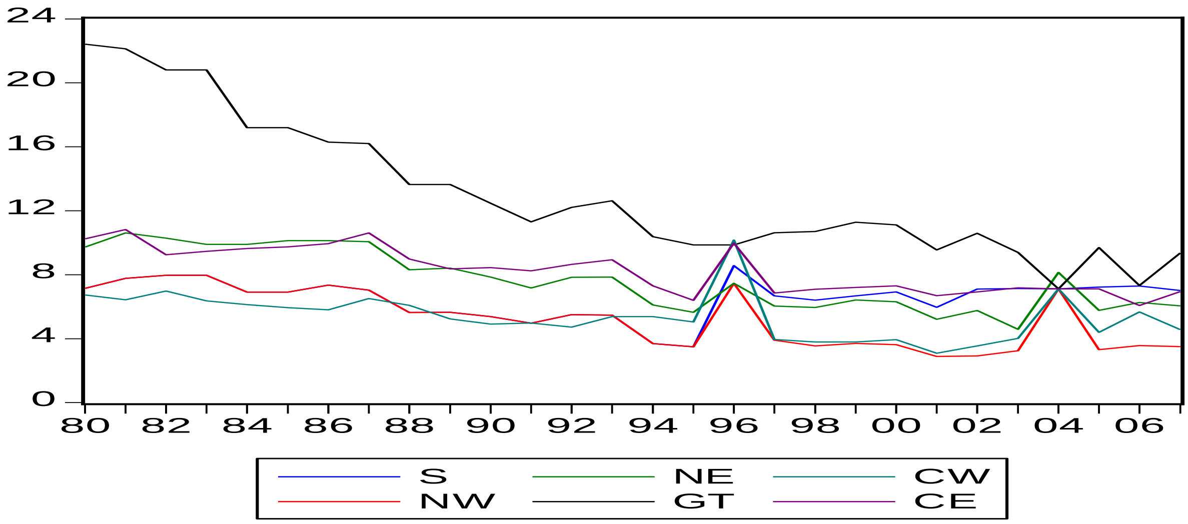

Figure 1. Annual average water consumption per area

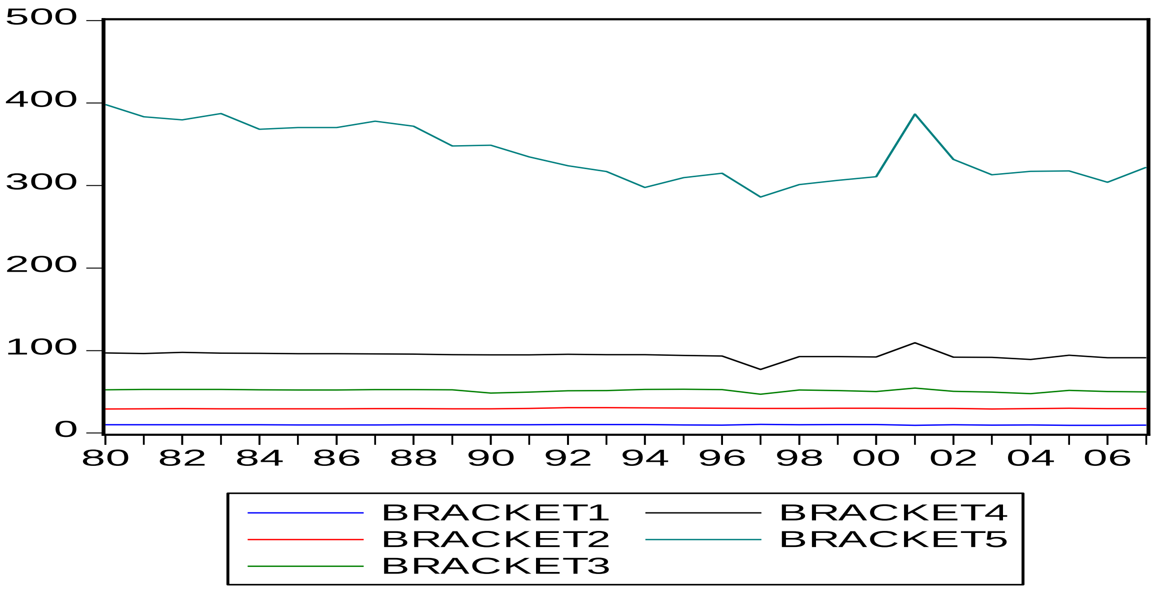

Figure 2. Annual average water consumption per brackets

Consequently, the best way is to conduct our estimation using the two-block decomposition method, rather than using the five-bracket method. We think that five-bracket decomposition would divert the consumer from rational behavior. The lower block will include the consumers of the first two brackets (0-40 m^3), while the upper block includes the last three brackets (over 41 m^3).

3. Econometric method

We begin by testing the panel unit roots, then we implement the seven tests proposed by Pedroni (1999) to obtain the long term relationship between all the variables. Then, we use the fully modified OLS (FMOLS) technique to estimate the cointegration vector for heterogeneous cointegrated panels, which correct the standard OLS bias induced by the endogeneity and serial correlation of the regressors.

The Levin, Lin and Chu (2002) test (LLC hereafter) was the first test in literature on non-stationary panel data which is inspired from the ADF test of time series. Thus, the LLC tests the null hypothesis of $\delta = 0$ for all cross-sections i, against the alternative of δ<0 from the following equation:

$$\Delta y_{it} = \delta y_{i,t-1} + \sum_{l=1}^{P_i} \theta_{ip}\, \Delta y_{i,t-1} + \alpha_{mi} d_{mt} + u_{it} \qquad (2)$$

where $d_{1t} = \emptyset$, $d_{2t} = \{1\}$ and $d_{3t} = \{1, t\}$ correspond to the three ADF cases.
The LLC proposes a three-step procedure to implement their test. The adjusted statistic used here is:

$$t_\delta^* = \frac{t_\delta - N \times \mathrm{std}(\delta) \times \mu_{m\tilde{T}}^* \times \hat{\sigma}_{\tilde{\varepsilon}}^{-2} \times \hat{S}_N \times \tilde{T}}{\sigma_{m\tilde{T}}^*} \sim N(0,1)$$

with $\frac{\sqrt{N}}{T} \to 0$.
where $\hat{S}_N$, $\mu_{m\tilde{T}}^*$ and $\sigma_{m\tilde{T}}^*$ are the average standard deviation ratio calculated in the second step, the mean and standard deviation adjustments simulated by the authors for different order of m and the time series dimension $\tilde{T}$ respectively (see Levin and al, 2002).

The Im, Pesaran and Shin (2003) test (IPS hereafter) is formulated by the LLC equation when m=2 and δ_i varies across cross-sectional units.
Thus, the IPS statistic tests the null hypothesis of $\delta_i = 0$ for all i, against the alternative of $\delta_i < 0$ $for\ i = 1, \dots, N_1$ and $\delta_i = 0$ $for\ i = N_1$ +1,…,N.
with $N_1 \in\ ]0, N[$, $such\ as$ $\lim_{N\to\propto}(^{N_1}/_{N})= \delta$ $where$ $0 \le \delta \le 1$.

if $N_1 = 0$, we find the null hypothesis.
The IPS uses the average of the individual ADF statistics defined as:

$$\bar{\mathbf{t}}_{\mathbf{NT}} = \frac{\mathbf{1}}{\boldsymbol{N}} \sum_{\boldsymbol{i}=\mathbf{1}}^{\boldsymbol{N}} \mathbf{t}_{\mathbf{iT}} \,(\boldsymbol{P}_{\boldsymbol{i}}, \boldsymbol{\beta}_{\boldsymbol{i}})$$

t_{iT}= (P_i, β_i) is the individual student statistic under the null hypothesis for a given lag order P_i and a vector of ADF coefficients
$\boldsymbol{\beta_i} = (\boldsymbol{\beta_{i,1}}, \boldsymbol{\beta_{i,2}}, \ldots\ldots\ldots\ldots, \boldsymbol{\beta_{i,p_i}})'$.
The IPS uses the standard normal statistic Z.

$$\bar{\boldsymbol{Z}} = \left[\sqrt{\boldsymbol{N}}\, \frac{(\bar{\boldsymbol{t}}_{\boldsymbol{NT}} - \boldsymbol{E}(\boldsymbol{t}_{\boldsymbol{iT}}))}{\sqrt{\boldsymbol{var}(\boldsymbol{t}_{\boldsymbol{iT}})}}\right] \xrightarrow[\boldsymbol{N}\to\infty]{} \boldsymbol{N}(\mathbf{0},\mathbf{1})$$

where the terms $E(t_{iT})$ and $var(t_{iT})$ are the mean and variance of each statistic respectively, and they are generated by simulations and tabulated in the IPS (1997).

After testing for stationarity of the variables, we then test for the existence of a long-run relationship among the variables. We apply the residual-based method developed by Pedroni (1999) where the cointegration rank is a priori known and equal to one. Thus, to test for the null of no cointegration in heterogeneous panels with multiple regressors, Pedroni [1999] considers the following regression;

$$\boldsymbol{y_{it}} = \boldsymbol{\alpha_i} + \boldsymbol{\delta_i}\, \boldsymbol{t} + \boldsymbol{\beta_{1i}} \boldsymbol{x_{1,it}} + \boldsymbol{\beta_{2i}} \boldsymbol{x_{2,it}} + \ldots\ldots + \boldsymbol{\beta_{Mi}}\, \boldsymbol{x_{M,it}} + \boldsymbol{\varepsilon_{it}} \qquad (3)$$

where $i = 1, \ldots\ldots, N$, $t = 1, \ldots\ldots, T$ and $m = 1, \ldots\ldots\ldots, M$.

T, N and M refer to the time series dimension, the number of cross sectional regions and the number of regression variables, respectively. Pedroni (1999) develops asymptotic and finite sample properties of testing statistics to examine the null hypothesis of non-cointegration in the panel. The tests allow for heterogeneity among individual members of the panel.

On the seven tests suggested by Pedroni, four tests are based on the within-dimension and three on the between-dimension. The two categories examine the null hypothesis of non-cointegration in the panel. The first approach includes four statistics. They are panel m-statistic, panel q-statistic, panel PP-statistic, and panel ADF-statistic. These statistics pool the autoregressive coefficients across different members for the unit root tests on the estimated residuals. The second approach includes three statistics. They are group q-statistic, group PP-statistic, and group ADF-statistic. These statistics are based on estimators that simply average the individually estimated coefficients for each member (see Pedroni, 1999, for more details).

4. Empirical estimation, comments and analysis of the main results

We begin our empirical estimation by testing the stationarity of our main variables, namely quarterly data for average water Consumption (C), average water Prices (P), Income (I), (This variable is constructed from the expenditure surveys by the National Statistics Institute), Rainfall (RL) and Network Expansion (NE).

	Lower block				Upper block			
	LLC		IPS		LLC		IPS	
	Trend	notrend	Trend	notrend	Trend	notrend	Trend	notrend
C	-2.21*	-1.9	-3.31*	-4.09*	-7.07*	-0.51	-10.9*	-0.81
P	-4.93*	-0.19	-6.22*	-0.22	1.94	-0.49	4.17	-0.67
I	-0.97	0.94	-1.06	1.04	2.61	3.59	1.66	0.71
NE	0.28	1.99	1.2	2.65	-0.48	1.04	-0.01	1.16
RL	-0.84	-1.18	-1.21	-1.91	-	-	-	-
ΔC	-27.4*	-25.7*	-39.6*	-39.8*	-16.06*	-19.2*	-26.7*	-25.6*
ΔP	-14.3*	-12.6*	-23.6*	-26.5*	-16.5*	-17.2*	-27.9*	-22.8*
ΔI	-17.01*	-17.56*	-28.1*	-29.2*	-1.06	-2.1*	-1.2	-4.7*
ΔNE	-11.16*	-13.6*	-14.3*	-14.9*	-18.03*	-21.7*	-24.1*	-23.7*
ΔRL	-18.57*	-18.1*	-31.2*	-30.56*	-	-	-	-

** Rejects the null of panel unit root at the 5% level.*

All the variables are in natural logarithms.

Table 1. Panel unit root tests

The outcomes of the panel unit root tests with and without trend are reported in Table 1. We clearly see that all the variables are not stationary for the two blocks. All the variables are integrated of order 1 *(I (1))*.

	Lower block		*Upper block*	
	Trend	*no Trend*	*Trend*	*no Trend*
Pedroni (1999) cointegration tests				
Panel-m	1.9	3.6	4.1*	5.8*
Panel-q	-14.6*	-15.9*	-21.8*	-23.6*
Panel-pp	-17.2*	-16.4*	-20.8*	-19.1*
Panel-adf	1.3	0.5	-18.8*	-15.6*
Group-q	-14.2*	-16.5*	-21.9*	-25.3*
Group-pp	-18.8*	-19.4*	-23.4*	-23.3*
Group-adf	2.3	1.4	-19.8*	-17.4*
* Rejects the null hypothesis at the 1% level.				

Table 2. Panel cointegration tests result

The results illustrated by Table 1 lead us to test the relationships between the average Water consumption (C) and its determinants (P, I, NE and RL). The seven tests proposed by Pedroni (1999) are implemented using Rats 7 software. We obtain without ambiguity a long-term relation between all the variables for the two blocks. All the statistics significantly reject the null of no cointegration. The main results are shown by Table 2.

We then conduct our estimation of individual and panel group coefficients by FMOLS which allows the estimation of the long-run relationship between non-stationary or integrated variables in the same order. The main results obtained by our estimation are summarized in Table 3.

Consumption bloc	*Lower block*				*Upper block*			
variables	*LnP*	*LnI*	*LnNE*	*LnRL*	*LnP*	*LnI*	*LnNE*	*LnRL*
			INDIVIDUAL	FMOLS	RESULTS			
CW	-0,15*	0,22*	-0,22**	-0,03*	-0,27*	0,7**	-0,14*	-0,03*
	(-2,23)	(2,54)	(-1,61)	(1,94)	(-10,3)	(1,5)	(-6,5)	(2,18)
CE	-0,1*	0,08*	-0,1	-0,005*	-0,3*	0,001	-0,12*	-0,02**
	(-1,97)	(2,02)	(-1,26)	(-0,62)	(-11,9)	(0,03)	(-4,8)	(-1,72)
NE	-0,1*	0,12	-0,04	-0,005	-0,35*	0,27	-0,14*	-0,01*
	(-1,82)	(1,26)	(-0,46)	(-0,56)	(-18,4)	(0,48)	(-8,5)	(-1,82)
NW	-0,25*	0,26*	-0,06	-0,03**	-0,46*	0,1	-0,23*	-0,07*
	(-3,64)	(2,52)	(-0,4)	(-1,77)	(-7,4)	(0,1)	(-5,1)	(-1,8)
S	-0,04	0,004	-0,23*	-0,01**	-0,32*	0,02	-0,2*	-0,02*
	(-0,8)	(0,04)	(-2,27)	(-1,73)	(-11,2)	(0,01)	(-7,2)	(-1,81)
GT	-0,08*	0,01	-0,07*	-0,02*	-0,24*	0,1	-0,02	-0,02*
	(-2,22)	(0,37)	(-1,87)	(-5,48)	(-6,23)	(0,2)	(-0,86)	(2,85)
		PANEL	*GROUP*	*FMOLS*	*RESULTS*			
Panel (without trend)	-0,12*	0,12*	-0,12*	-0,008*	-0,32*	0,2	-0,14*	-0,01
	(-5,18)	(3,57)	(-3,22)	(-3,35)	(-26,8)	(0,96)	(-13,5)	(-0,86)
Panel (with trend)	-1,4*	0,06*	0,01	0,001	-1,09*	0,08*	-0,11*	-0,1
	(-87,7)	(3,46)	(-0,22)	(-1,7)	(-4,7)	(2,1)	(-4,1)	(-0,16)

* indicates statistical significance at the 5% level.
T-statistics in parenthesis. The variables are in natural logarithms.

Table 3. FMOLS estimation results

As we see from this table, the results are statistically significant and in accordance with the intuitions and the theoretical requirements. If we go toward a sound analysis of all the estimations presented, we can put forward the idea that all the price elasticities have the right sign and are significant (with only one exception). We can then conclude that the water prices for the lower block are inelastic, as expected, while those for the upper one are rather elastic.

Our estimation results are comparable to the results obtained in other similar studies. However, the income elasticities have the right sign but are generally statistically insignificant. We conclude also that the negative impacts of the rainfall on the Tunisian water demand are important for all the regions and for the two blocks. The network extension effects are significant but weak, and this is due to the fact that the Tunisian water network, following rapid extension, is now becoming stable.

The estimations with the panel data are good and confirm the previous studies. Indeed, the price elasticities are different between the six regions. This difference is related to climate effect which is not equal in magnitude between dry and wet areas. Therefore, it is evident from our estimation that the water demand model cannot be estimated without the climate variable. We must mention that the elasticities obtained here, which rely on extended data and a new econometric technique, are rather the same as those obtained by Ayadi et al (2002). This leads us immediately to state that the price elasticities of the Tunisian water demand are now well estimated and we can rely on them to design appropriate recommendations for the decision makers in this strategic sector.

5. ***Conclusion and policy recommendations***

Our results show that water demand management must be considered seriously in Tunisia as well as in similar regions. For the upper block, appropriate pricing will lead to a reduction of water consumption and better conservation of this scarce and precious resource. However, the pricing instrument must be combined with the arsenal of the non-price instruments such as water conservation and participatory allocations. The best way will be to design a toolkit of integrated measures which will properly combine the price and non-price instruments. For the lower block, which is composed essentially of low-income households characterized by inelastic water demand, all tariff increases will certainly deteriorate their wellbeing. Indeed, this category has the opportunity to satisfy only its essential needs and is unable to reduce water consumption even at the price of impoverishment.

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