WATER SUPPLY INTERRUPTION: DOES LENGTH MATTER? AN EMPIRICAL APPLICATION TO RESIDENTIAL USERS IN SEVILLE

Maria A. García-Valiñas[a,b]

David Roibás[a]

Abstract:

EU Water Framework Directive leads to manage water in an efficient way. Water scarcity originates frequently the need for rationing, and various methods, including supply interruptions, can be used. The aim of this paper is to evaluate the effectiveness and efficiency of those methods in reducing residential water consumption. We estimate a demand function segmented into two components in order to capture the proportion of water consumed by households under different supply cut schemes. We find that the reduction in consumption per hour of cut decreases with the length of the daily interruption. Thus, it is better to implement many short cuts than a few long cuts in order to achieve the targeted reduction in consumption, minimizing the total time of interruption. Additionally, we show the relative effectiveness of prices to control water demand.

Keywords: consumer behaviour, water services, supply interruption, welfare economics,

***JEL classification**:* D11, D60, Q25

[a]Department of Economics, University of Oviedo

[b]Corresponding author: Maria A. García-Valiñas
Department of Economics, Faculty of Economics, University of Oviedo, Avenida del Cristo, s/n, 33071, Oviedo (Asturias), Spain.
Tel: + 34 985 10 48 78.
Fax: +34 985 10 48 71.
E-mail address: mariangv@uniovi.es

1.- Introduction

Traditionally, water has been considered as one of the most important natural resources and its availability has conditioned the location of economic activity (Gibbons 1986). At the same time, water is a limited resource that has given rise to numerous conflicts over its allocation between alternative uses (Lee 1999). The importance of water lies in the fact that it satisfies a broad group of needs, both in its role as a necessary good upon which public health and life itself depend, as well its role as a basic input in most agricultural and industrial production processes. This double role of consumption good and factor of production makes water an essential factor in economic activity and obliges the authorities to invest in infrastructure which guarantees its availability, often at a high cost.[1]

Demographic pressure and the process of economic development lead to a continual increase in the consumption demand for water, while at the same time the climatological conditions which limit the availability of water in many geographical zones appear to be worsening as a consequence of the process of climatic change which the planet is undergoing.

[1] In Spain, for example, the contrast between regions in terms of the natural availability of water has led to a policy of diverting water between basins. The National Water Plan approved in 2001, which aims to improve the water supply in regions in the south of Spain on the Mediterranean coast, has an estimated cost of around 3.78 billion euro. This Plan was abandoned by the new government in 2004, which supports conservation policies and desalinization plants in Southeastern Spain as an alternative.

Those factors have the effect that periods of water shortage can be expected to reappear in the future. This in turn will give rise to the need for policies which limit consumption. In particular, one of the most serious causes of water shortage in many regions is drought, and when this cyclical phenomenon reoccurs the entities responsible for water supply often impose water cuts in order to match the available supply with demand. Generally, water shortages give rise to the need for rationing, and while the authorities frequently resort to supply cuts, there are various other ways in which this can be achieved (Winpenny 1994).

EU Water Framework Directive leads to manage water in an efficient way. So it would be really interesting to find out what rationing method is more efficient and effective to control water consumption. Several studies have focused on the effects of policies aimed at limiting water consumption (Moncur 1987; Woo 1994; Renwick and Archibald 1998; García-Valiñas 2006; Roibás et al. 2007). In this paper, we evaluate the impact in consumption of several rationing regimes: supply interruptions and price rises. Additionally, we are interested in finding out what kind of hourly interruption framework is more efficient in order to control residential water consumption. We apply the model to analyze the effects caused by the drought which affected the city of Seville (Spain) in the first half of the 1990s.

We proceed as follows. In Section 2 we describe the effects of the drought in Seville in the early 1990s and the main initiatives implemented by the supplier in response. Section 3 presents the theoretical model used for the empirical analysis. Section 4 shows the empirical specification. Data set is described in Section 5, and the estimates and welfare results are shown in Section 6. Section 7 concludes.

2.- The drought in Seville in the early 1990s

Seville is a city in the south of Spain with more than 700,000 inhabitants (INE 2006) which has been severely affected by scarcity problems several times. The drought during the first half of the 1990s will be the focus of our attention. The shortages appeared at the end of 1991 and the situation worsened the following year, which coincided with Expo '92[2]. The first restrictions on consumption, formally introduced through the publication of municipal edicts[3], were put into place at the beginning of 1992. These edicts specified the conditions under which water would be supplied as well as the response which was expected from users.

The restrictive measures put into practice comprised cuts in supply and reductions in water pressure. Hour restrictions were particularly intense during the years 1993 and 1995. During this period, water cuts sometimes lasted for up to twelve hours per day[4]. Regarding the structure of interruptions, the shortest (basic) cuts went from 2 a.m. to 6 a.m. If public authorities decided to increase the duration of the daily interruption period, then they extended the basic cut towards the last hours of the night and evening.

[2] The World Fair which took place in the city in 1992.

[3] Although supply cuts are legally permitted under certain circumstances, it is obligatory to notify users in advance about when the cut will take place, as well as the intensity and the estimated duration (Molina 2001).

[4] Those restrictions were not applied to users, such as health centers, providing services deemed to be essential to the public interest

Apart from restrictions on the hours of water availability, the quality of the resource was also affected. Despite the efforts of the supplier to guarantee water quality, the special circumstances of the weather and the consequent decision to diversify the sources of provision led to a considerable deterioration of the resource. The health authorities found themselves with no other option but to implement a provisional relaxation of water standards using the argument that this was a period of "exceptional conditions".

3.- The model

In this section, we design a model which captures the influence of temporary unavailability of the resource on consumer demand. These temporary interruptions have two main observed effects on consumer behavior. Firstly, consumers react to an interruption by acquiring only a proportion of the water that they would have consumed had there been no cut[5]. Secondly, the longer the duration of the interruption, the lower the proportion of water acquired. It should be noted that consumers can install devices such as storage tanks to soften the impact of interruptions. These expenditures will in turn generally depend on household income. We therefore expect that the reduction in consumption due to the supply interruptions may also depend on household income.

To capture the aforementioned characteristics, we model a marshallian water demand function comprising two components as follows:

[5] Consumers are able to maintain their overall water consumption at pre-interruption levels if they so wish (by consuming at times when water is available). Changes in consumption due to the interruption are therefore a consequence of changes in consumer behaviour induced by the cut.

$$Q = Q[p,y,s;f(c,y)] = q(p,y,s)\cdot f(c,y) \qquad (1)$$

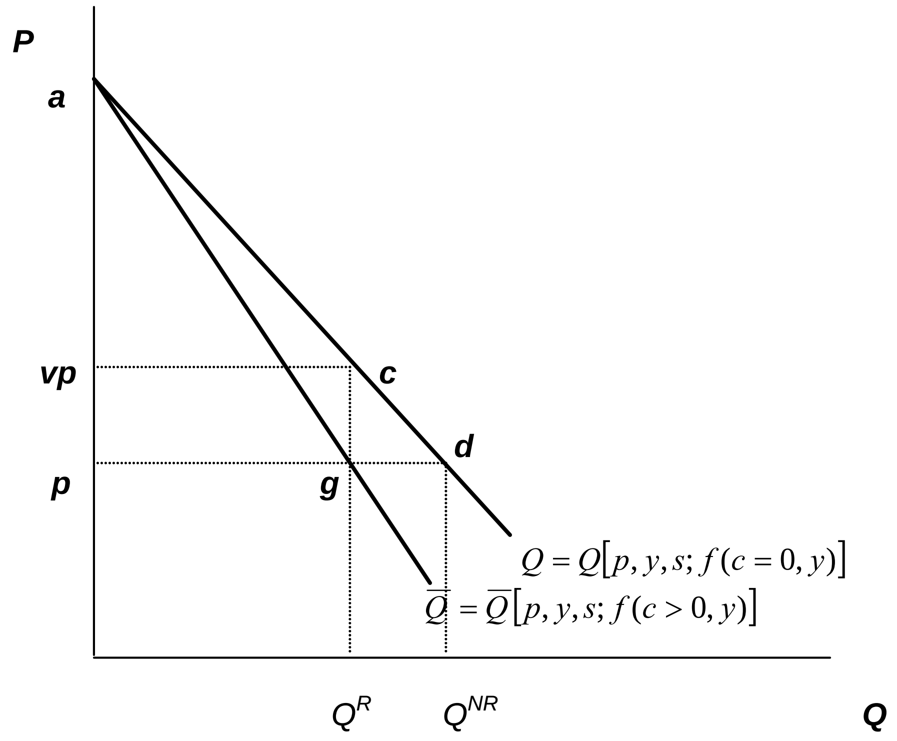
The first component, $q(\cdot)$, represents a standard marshallian demand function which depends on the price of the rationed good (p), income (y), and other variables which affect the utility of the consumer (s). The second component, $f(\cdot)$, is a function which captures how the duration of the interruption (c) and the household income (y) determine the proportion of the desired good that the consumer acquires when a supply cut takes place.

It is assumed in this model that the amount of consumption loss due to the supply cut depends on the planned consumption and therefore on the variables which determine this planned consumption. However, it is also assumed that the consumption lost as a proportion of planned consumption depends only on the duration of the cut and household income. In this sense, the effect of the interruption is similar to that of a proportional rationing scheme (see, for example, Tirole 1988), under which consumers only acquire a certain proportion of their desired quantity of the good.

Figure 1 shows the water demand function consistent with the assumptions maintained in the model under two different scenarios. When there are no interruptions, the water demand curve is represented by Q, whereas $\overline{Q}$ represents the demand function when supply interruptions are in place. Thus, the introduction of a water cut induces a reaction on the part of consumers such that the water demand curve moves from Q to $\overline{Q}$, reducing the quantity demanded, given the price, from Q^{NR} to Q^{R}.[6]

Figure 1

Welfare losses: good water quality

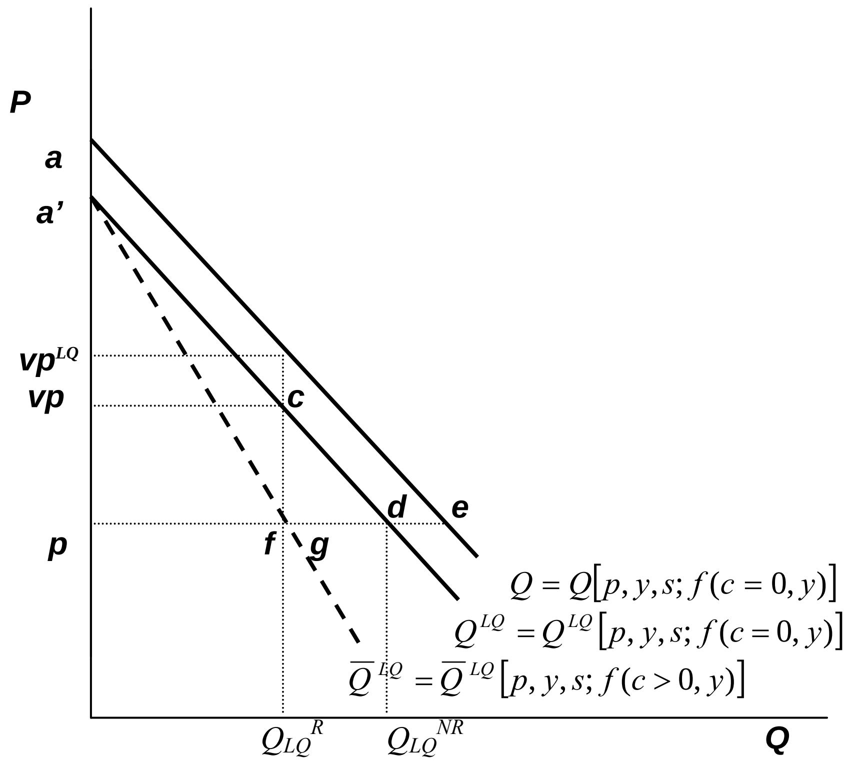


[6]It is implicitly assumed in the model that the intercept of the demand function does not change when a supply cut takes place. This may be questionable in the sense that the intercept of the demand function refers to the most valuable unit of the good and it could therefore be argued that this value may change when an interruption of supply occurs. However, as households are able to store a certain amount of water when the supply cut is announced, this storage capacity will assure the consumption of the most valuable unit and as a result it can be argued that its value does not change.

Additionally, under water quality reductions, the price which consumers will be willing to pay for the first m^3 would be reduced. It is possible to observe the previous idea in the Figure 2, in which demand function moves taking into account both shortages and quality reductions.

Figure 2

Welfare losses: bad water quality



Based on this modeling of the marshallian demand function, we propose using the consumer surplus as an approximation to the welfare losses associated with the distinct rationing systems. In the basic scenario (good water quality, see Figure 1), the introduction of a water cut has the effect that consumer surplus is reduced by:

$$\nabla W^{C} = \int_{p}^{a} Q[p,y,s;f(c=0,y)]\,dp - \int_{p}^{a} \overline{Q}[p,y,s;f(c>0,y)]\,dp \tag{2}$$

We compare the effects on welfare of the interruption with those which would arise from a policy of rationing via prices. To do so, we need to determine how much the price should be raised in order to obtain a similar effect to that of the interruption. That is, from the demand function we need to determine the virtual price (*vp*) which would give rise to a reduction in consumption equivalent to that which would occur under a given interruption. Raising the price to *vp* therefore represents an alternative, but equally effective, method of rationing, and the corresponding loss in consumer surplus would be (area *vpcpd)*:

$$\nabla E^{P} = \int_{p}^{vp} Q[p,y,s;f(c=0,y)]\,dp \tag{3}$$

However, part of this variation is accounted for by a transfer of rent to the supplier. As water provision is typically regulated by the public sector, these rents may return to consumers through public spending. Under this scenario, the net loss in social welfare is:

$$\nabla W^{P} = \int_{p}^{vp} Q[p,y,s;f(c=0,y)]\,dp - (vp-p)\cdot Q^{R} \tag{4}$$

Comparing (2) and (4) using Figure 1, it can be seen that the welfare loss under price rationing is always lower than that corresponding to an interruption. This result is due to the fact that under a price rise consumers only acquire units of the good which they value more than *vp.* This implies that consumers forego the marginal units of water. Under an interruption, on the other hand, they acquire units which they value more than *p* as long as they are available. However, an interruption may prevent consumption of certain units of the good valued by the consumer above *vp* which are substituted by other units valued between *p* and *vp* which are available. This implies that the consumer foregoes units of water which are not necessary the marginal ones, implying a further loss in consumer welfare.

Finally, we adjust welfare losses considering water quality. We are assuming that water supplier is not able to control input water quality, due to the extreme conditions to supply under drought period. Based on Figure 2, welfare losses liked to water quality (area *aa'ed*) can be calculated by the following expression:

$$\nabla W^{LQ} = \int_p^a Q\left[p,y,s;f(c=0,y)\right] dp - \int_p^{a'} Q^{LQ}\left[p,y,s;f(c=0,y)\right] dp \qquad (5)$$

Additionally, it would be possible to recalculate virtual prices in the new context (vp^{LQ}). This virtual price would approximate the valuation that users give to quality water resource and service, without any quantity or quality restrictions. So, by means of this virtual price, scarcity costs of water resources could be approximated.

4.- Empirical specification

In order to estimate the marshallian demand in equation (1), we propose the following empirical specification:

$$Q_{it} = \left[\beta_0 + \beta_p p_{it-2} + \beta_y y_i + \beta_n n_i + \beta_{qual}\, qual_t + \beta_{temp}\, temp_t\right] \left[1 + d_h\left(\alpha_s + \alpha_s y_i + \alpha_s c_t^s + \alpha_l c_t^l\right)\right] \qquad (6)$$

Quantity of water (*Q*) total household consumption per period. The demand function in equation (1) measures is specified as the product of two components. The first component represents the marshallian water demand in the absence of supply cuts, modeled as a linear relationship, where (p_{it-2}) is the price that the ith consumer pays for water in period t-2; (y_i) is the consumer's income, $(temp_t)$ is the average temperature in the period t, (n_i) is the number of persons in the consumer's household and $(qual_t)$ is a dummy variable indicating the presence of water quality reductions during the period. The second component captures the effect of the interruption on the quantity of water acquired, where (d_h) is a dummy variable which equals 1 when interruptions takes place. Thus, we have differentiated between a "short cut" (c^s_t), which includes the total supply cut duration in the period t when marginal supply interruptions are minor or equal than six hours per day, and a "long cut" (c^l_t), which considers the global duration of the interruption when daily cuts are longer than six hours per day. This second component includes income too. Finally, α and β are parameters to be estimated.

5.- Data set

To estimate equation (6), we have used a balanced panel consisting of quarterly observations corresponding to 208 Sevillian households with individual meters, covering the period from the fourth quarter of 1991 to the third quarter of 2000. The data come from several sources. The Sevillian municipal water supply firm (EMASESA) provides information about water consumption per household (Q), the price of water and the presence of restrictions into the quality of the water supplied (*qual*). The price is calculated as the average quantity paid per cubic metre, which is regarded as the most appropriate indicator in a framework of imperfect information (Charney and Woodard 1984; Opaluch 1984). The two-period lag in the price is introduced to capture the fact that users only observe the price when they receive the bill. The complexity of the water rate structure means that the bill thus becomes a crucial informative tool for users. The bill is received, however, during the quarter following consumption, so consumers can only react to variations in the price after two periods, hence the two-period lag. Quality variable (*qual*) is equal to 1 when there are drops in pressure and/or chemical parameters which determine the quality of the product.

A proxy for the family income *(y)* is obtained from an estimation performed by La Caixa for the year 1998 (La Caixa 2000). We use a proxy based on the location of the home within the municipality. The Revenue Office of the Municipality of Seville provides information on the fiscal category of each street, and for each category an interval of disposable income has been assigned. The estimates for available income are provided by a research study carried out by La Caixa for the year 1998 (La Caixa 2000). There are eight income intervals in total, and the mean of each interval is used to approximate family disposable income.

The data about temperature *(temp)* are provided by the Spanish National Meteorological Institute. We use the arithmetic mean of the maximum daily temperatures during the period under consideration.

Finally, the number of users per household (*n)* has been obtained by dividing the total number of people in each building who appear in the census by the number of households in each building. However, we could get the “real” number of people for household in the case of “large families” (4 o more members), due to the application of discounts in water tariffs depending of household size. Anyway, difficulties in getting information prevent us from determining how the number of people in each household varies over time. Hence, the variable only exhibits variation across the different households and does not change over time. The information on this variable is provided by Seville City Council and EMASESA.

Some descriptive statistics relating to the variables and the quantities consumed are presented in Table I.

Table I

Variables used in the estimations: descriptive statistics

Variable	Units	Mean	Stan. Dev.	Max.	Min.
Q	*m*^{3}	108.69	150.48	527.84	1.90
p	*Euros/m*^{3}	1.43	0.37	2.22	0.85
y	*Euros/household*	2426.73	471.06	3693.25	1652.24
temp	*Celsius Degrees*	25.54	5.32	32.6	18.1
n	*Persons/House*	3.78	2.11	11.00	1.00
c^{day}	*Hours: Minutes*	4:50	2:03	7:00	0:40

Source: own elaboration

[a] When calculating the statistics referring to the duration of the interruption we exclude periods for which there are no interruptions.

6.- Results

The estimation was carried out using a non-linear least squares estimator[7]. The parameter estimates are presented in Table II.

Table II

Demand function: estimates

Parameter	Estimate	Std. Error	t-statistic
α_0	-0.323075 ***	0.069595	-4.6422
$\alpha_1\ (y)$	0.000085 ***	0.000025	3.4061
$\alpha_2\ (c^s)$	-0.000350 ***	0.000075	-4.6759
$\alpha_3\ (c^l)$	-0.000170 ***	0.000036	-4.6948
β_0	-103.0780 ***	8.7936	-11.7220
$\beta_1\ (p)$	-31.5009 ***	3.7738	-8.3473
$\beta_2\ (y)$	0.0033	0.0024	1.3708
$\beta_3\ (temp)$	0.8970 ***	0.2010	4.4624
$\beta_4\ (nper)$	62.7401 ***	0.6230	100.7020
$\beta_5\ (qual)$	-22.7933 ***	2.6885	-8.4782
R^2	0.69		

Source: own elaboration

Parameters α_2 and α_3 show that the effectiveness of an hour of supply cut in reducing consumption depends on the number of hours per day that the supply is interrupted. When supply cuts are minor than six hours per day the reduction in consumption per hour of cut is greater than the reduction achieved when supply interruptions are major than six hours per day. This finding allows us to support the idea than it would be more efficient to interrupt supply by means of several short periods instead a few long ones. With shorter cuts, it would be possible to get an aim of consumption reduction, minimizing the total duration of interruption and users' welfare losses.

[7] See Greene (2002), chapter 9, for details.

The (own) price elasticity of demand of water, calculated at the arithmetic mean of price and quantity demanded, is -0.41. This result is consistent with existing studies on water demand (Arbues et al. 2003). Thus, prices are not a very effective rationing instrument in the water context. Additionally, the parameter which captures the influence of income on water demand is positive but not statistically significant. However, as we can see high income users seem to have more possibilities to install higher storage capacity, reducing in this way the impact of supply cuts on consumption. So, this result shows that rationing by means of supply interruptions is a policy which has clearly regressive effects. The remaining variables show the expected signs. Quality reductions lead to very significant reduction in consumption. Finally, temperatures and the number of people in household have a positive and significant impact in water demand.

Regarding welfare simulation exercise, we have based on the results of the demand estimation. Thus, we consider two alternative scenarios: the first is when there are no restrictions on the quality of water provided (*QUAL* = 0), and the second when there are restrictions on quality (*QUAL* = 1). Additionally, we consider both short and long cuts. From the estimates, and taking the average values of the variables we calculate: a) the loss of surplus caused by the average interruption (∇W^C), b) the net welfare loss associated with pv (∇W^p) and finally c) welfare loss associated with quality reduction (∇W^{LQ}). Table III shows the simulation results. Notice that, in order to observe the impact of several means of rationing (prices and supply interruptions), it would be necessary to compare ∇W^p with ∇W^C.

Table III

Welfare simulation

	QUAL=0		QUAL=1	
	$c^{s(=223)}$	$c^{l(=545)}$	$c^{s(223)}$	$c^{l=(545)}$
Q^{NR}	120.02		97.23	
$\downarrow Q$	-23.28	-25.00	-18.86	-20.25
p	1.43		1.43	
vp	2.17	2.23	2.03	2.07
vp^q	---	---	2.75	2.80
∇W^c	44.34	47.62	29.10	31.25
∇W^p	8.60	9.92	5.64	6.51
∇W^{LQ}	---	---	78.60	

Source: own elaboration

In the previous table and as we expected, we observe that welfare losses are higher during the periods in which long interruptions are applied. Additionally, we observe that the main welfare losses are due to water quality reductions. Scarcity and quality problems are shown in virtual prices values. When water quality is low, residential users would be able to pay almost twice the real price.

6.- Conclusions

Water scarcity is a cyclical problem which water suppliers have to deal with. In this research, we have focused on analyzing the efficiency and effectiveness of supply cut, one of the most usual procedures to manage droughts. In an empirical application, we study the effects of the interruptions imposed by the Sevillian authorities during the drought in the mid-1990s. At this respect, we have found that shorter and more frequent cuts are preferred to few longer cuts. That procedure allows getting a planned reduction in residential water consumption minimizing the total hours of interruption. Moreover, we find that supply cuts are regressive in the sense that the higher the level of household income, the lower the effect of the cut. This is consistent with the fact that higher income households have easier access to water storage technologies. Additionally, regarding other rationing methods, we have obtained, as in previous studies, a low price-elasticity value. Definitively, those are very significant findings in order to design rationing policies in the context of water field.

References

Arbués, F., M. A. García-Valiñas, and R. Martínez-Espinera (2003). Estimation of residential water demand: A state-of-the-art review. *The Journal of Socio-Economics,* 32, 81-102.

Charney, A.H. and G.C. Woodard (1984). A test of consumer demand response to water prices: Reply. *Land Economics,* 60, 414-416.

García-Valiñas, M.A. (2006). Analysing rationing policies: drought and its effects on urban users' welfare. *Applied Economics,* 38(8), 955-965.

Gibbons, D.C. (1986). *The Economic Value of Water*. Washington, D.C.: Resources for the Future.

Greene, W. H. (2002). *Econometric Analysis*. New Jersey: Prentice Hall .

INE (2006). *Cifras de Población Referidas al 1/1/06. Población de Municipios por Sexo*. Madrid: Instituto Nacional de Estadística.

La Caixa (2000). *Anuario Comercial Español*. Barcelona: Servicio de Estudios de La Caixa.

Lee, T.R., (1999). *Water Management in the 21st Century: The Allocation Imperative*. Cheltenham: Edward Elgar Publishing.

Molina, A. (2001). *El Servicio Público de Abastecimiento de Agua en Poblaciones. El Contexto Liberalizador*. Valencia: Tirant lo Blanch.

Moncur, J. (1987). Urban water pricing and drought management. *Water Resources Research,* 23, 393-398.

Opaluch, J. (1984). A test of consumer demand response to water prices: Reply'. *Land Economics,* 60, 417-421.

Renwick, M.E. and S.O. Archibald (1998). Demand side management policies for residential water use: Who bears the conservation burden?. *Land Economics,* 74, 343-359.

Roibas, D., Garcia-Valiñas, M.A. and Wall, A. (2007). Measuring welfare losses from interruption and pricing as responses to water shortages: An application to the case of Seville. *Environmental and Resource Economics*, forthcoming.

Tirole, J. (1988). *The Theory of Industrial Organization*. Cambridge: The MIT Press.

Winpenny, J. (1994). *Managing Water as an Economic Resource*. London: Routledge.

Woo, C. (1994). Managing Water Supply Shortage. Interruption vs. Pricing. *Journal of Public Economics,* 54, 145-160.