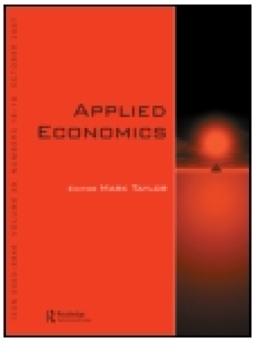

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How much does water consumption drop when each household takes charge of its own consumption? The case of the city of Seville

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How much does water consumption drop when each household takes charge of its own consumption? The case of the city of Seville

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Making individuals take charge of their own domestic water consumption is one of the measures used to reduce the growing demand for this resource and to achieve sustainable consumption compatible with the goal of equity. The use of individual meters instead of communal meters and fixing tariffs by inhabitant rather than by household are two measures aimed at achieving these objectives. This article assesses the measures put in place in the Seville metropolitan area during the last 20 years with an unobserved component model set up in a state-space framework estimated using maximum likelihood. Water consumption elasticity to individual meters has changed from –0.307 to –1.317 with the introduction of per inhabitant tariffs, which demonstrates that there are water-saving synergies when the two measures are implemented together. The reductions in water consumption achieved with these measures are also longer lasting than the changes in consumption habits during the frequent droughts in Seville.

Keywords: water management; equity; individual water meters; unobserved components models

JEL Classification: C22; L95; H40; Q25; Q21

I. Introduction

Broadly speaking, the water supply, which is as important for the ecosystem as it is for the population, is under threat from the ever increasing demand for water brought about by population growth, urban development, industrialization and rising standards of living. Given the unfavourable outlook of a water shortage characterized by competition for water use from agriculture, industry, households and environmental demands, there is an evident need for attitudes to water to be defined.

At the beginning of this new century, it would seem that there has been a change in the way that the water issue is being handled as far as water management policies are concerned, as demand policies have supplanted traditional supply policies (Arbués *et al.,* 2003; Barberán and Arbués, 2009). In general terms, demand management measures focus on programmes to heighten awareness, to encourage

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*Corresponding author. E-mail: jignacio@us.es water saving and to penalize wastage, including improved metering and the restructuring of tariffs.

The first of these measures, heightening awareness and educating people about water conservation, is a noteworthy measure, but its effects tend to be long term as not all the voluntary changes in user behaviour are immediate. However, the last two changes cited, changes to the tariff structure and improved metering, have had more immediate effects. This is why the goal of this paper is to analyse the consequences for domestic water consumption of these two measures. These measures are analysed in the Seville metropolitan area. The case of Seville has been analysed in a range of papers (Del Moral-Ituarte and Giansante, 2000; Martínez-Espiñeira and Nauges, 2004; García-Valiñas, 2006) due to its climate, which is extremely hot in the summer, and its recurring droughts. This article complements earlier work from a completely original angle, both with regard to the problem it aims to solve and the methodology used to do so. To be specific, the way domestic water consumption has evolved in Seville and the policy demands implemented by the municipal company that supplies water to Seville (EMASESA) are examined for the last two decades. We focus on evaluating two policies, subsidies for the installation of individual water meters, known as the *Plan Cinco*, and the changes made to the tariffs in recent years.

These two measures, meters and tariffs, are interlinked. The tariff structure is considered by some authors (Arbués *et al.,* 2003) to be the main instrument for controlling demand. However, there is no consensus with respect to the best price structure, as in each particular case the ideal system will depend on the features of the population, user preferences and the specific goals of the public authorities (Barberán and Arbués, 2009). There are three main goals: efficiency, cost recovery and equity (Dandy *et al.,* 1997; Montginoul, 2007). In Spain, the equity of urban water tariffs has become the object of intense social debate (Arbués and Barberán, 2012). Specifically, in the Seville metropolitan area fairness and equity have been the main guiding principles on which EMASESA says it has based its tariff system. The current water tariff is a two-part rate structure of a fixed quota and a variable quota, with the latter split into three blocks with progressive increases in price (increasing-block tariff), as recommended by the majority of the academic literature for simultaneously achieving the dual goals of equity and efficiency (Whittington, 1992; Arbués *et al.,* 2003; Montginoul, 2007; Barberán and Arbués, 2009). Billing by block is also set according to the number of people registered as residents of each household.

However, the current tariff structure has gradually been built up since the end of the 1990s with the aim of avoiding the issues that progressive tariffs might cause in water bills for households with a high number of members or buildings with communal meters; issues were acknowledged, not just by the economic literature (Whittington, 1992; Montginoul, 2007; Barberán and Arbués, 2009) but by the Spanish legal system (see Arbués and Barberán, 2012). At the present time we have reached a point where billing depends on the number of people who are resident in a household. The beginning of this new philosophy can be traced back to 2006, when the rebate for domestic consumption in the basic block was linked to the real number of registered residents in the household.

The *Plan Cinco* was launched in 1997 as a complement to this change in the tariff with the aim of encouraging residents associations to swap their communal water meters for individual meters. In the metropolitan area served by EMASESA, a large part of domestic consumption occurs in buildings that have a single communal meter, which makes it difficult to use stepped pricing and, therefore, calculate rebates. The fact that communal meters are widespread leads to a perverse incentive for greater water consumption; as everyone pays the same, it favours the highest consumers and penalizes the lowest consumers. A moral hazard thus rears its head in the sense that it is difficult to determine what contribution the consumer has in total consumption of water of the housing (Nauges and Thomas, 2000).

There are certain socio-psychological and behavioural connotations in this behaviour that should be taken into account in authorities' management of water demand (Gregory and Di Leo, 2003). In our case, the use of individual meters has an important psychological component as water savings are more obvious when individuals perceive that other consumers are also conserving water (Berk *et al.,* 1980; Jorgensen *et al.,* 2009). In other words, if someone sees, or simply assumes, that his/her neighbours are wasting water, this has a demotivating effect and the said person's efforts to save water, or any other resource, will be diminished and as a result his/her consumption will rise (Corral-Verdugo *et al.,* 2002). This would be a *Tragedy of the Commons* and, therefore, lead to overexploitation of water resources. There is also an obvious economic explanation. To wit, any individual who forms part of a group has an effective marginal cost for additional consumption that is lower than the price of said consumption, and this cost falls further, the greater the number of people who share the cost jointly.

At the end of the 1990s, Del Moral-Ituarte and Giansante (2000) considered that although the change from collective water meters to individual household water meters in Seville could result in considerable savings in water use, they were being installed at a very slow pace. This is the reason why, 12 years on, it is possible to analyse empirically the impact of this measure and the other above-mentioned changes to the tariff structure. Furthermore, the two measures will be assessed using a robust econometric time-series model.

II. Data

The relevant database available consists of primary data from different institutions and public companies (like EMASESA and the Spanish National Statistics Institute), running from January 1995 to September 2010:

A. **The endogenous variable** is the mean daily water consumption for domestic use per thousand inhabitants in the Seville metropolitan area in a given month.

B. **The exogenous variables** are as follows:

B.1. **Dummy exogenous variables:**

B.1.1. **Easter**: the so-called Easter effect. Here an attempt is made to discover whether there is a variation in domestic water consumption detectable in the month when the Holy Week is celebrated. Given the great importance of Holy Week in the city, where it is a major moving festival, a rise in domestic water consumption is expected.

B.1.2. **Business**: number of working days in the month. Unlike other fields of research where this variable has a clearer effect, *a priori* it is not easy to deduce the direction of causation between this explanatory variable and the dependent variable under study. This business-day variable is built as the number of working days less 5/2 times the number of non-working days.

B.1.3. **Droughts**: This variable refers to water reserves in the reservoirs that supply Seville expressed as a percentage of their total capacity. This variable enables it to be seen whether droughts produce a greater awareness of water consumption among the population as the value of this variable decreases. In general terms, water conservation is more evident when individuals believe that water is scarce (Jorgensen *et al.,* 2009). In some of the cases studied, drought triggered changes in attitude in residents with a change in their appreciation of water that would affect greater their future responsibility (Aini *et al.,* 2001).

The three drought periods in the data sample are treated in the analysis as step dummy variables (previous droughts have already been analysed in the literature, e.g. García-Valiñas, 2006):

(a) From May 1999 to December 2000.
(b) From September 2005 to October 2006.
(c) From August to December 2009.

B.1.4. There have been other one-off effects that have impacted on water consumption sporadically and which have been captured empirically using statistical methods. The automatic detection of outliers is one of the strengths of this model. In this respect, any event that alters the normal evolution of the city or its metropolitan area will be taken into account, such as a general or heavily supported local strike, an atypical change in the meteorological conditions, or even any technical incident that could have had a positive or negative effect on domestic water consumption during the said period.

C. **Economic activity in Seville:** the unemployment rate in Seville province has been used as a proxy variable of the economic cycle. This income variable is a factor that has regularly been considered in water consumption models (Dandy *et al.,* 1997; Gaudin, 2006), although the positive or negative correlation with domestic water consumption is controversial. Some authors, such as Musolesi and Nosvelli (2011) and Martínez-Espiñeira and Nauges (2004), report nonsignificant relationships, others report positive income elasticities (Nauges and Thomas, 2000; Domene and Saurí, 2006), while still others (Campbell *et al.,* 2004) argue that a greater income level entails the use of goods with more efficient water use, resulting in lower water consumption.

D. **Meters:** this variable measures the number of water meters per building. To be precise, it is the ratio between the overall number of water meters in all the municipalities in the Seville area served by EMASESA during each month and the total number of dwellings located in said municipalities, expressed as a percentage. In Seville the number of water meters per building has followed a constant upward trend due to a number of factors, such as the EMASESA policy to encourage the installation of individual meters (*Plan Cinco*), the new local building bylaws, which enforced the installation of individual meters, and also the trend towards single-family housing in dormitory towns around Seville. It is expected a priori that water consumption falls as the number of water meters rises.

E. **Tariff**: as discussed in the Introduction, price and tariff structure have an influence on domestic water consumption. The effect of the new tariff philosophy has therefore been taken into account as an artificial step dummy variable from January 2006.

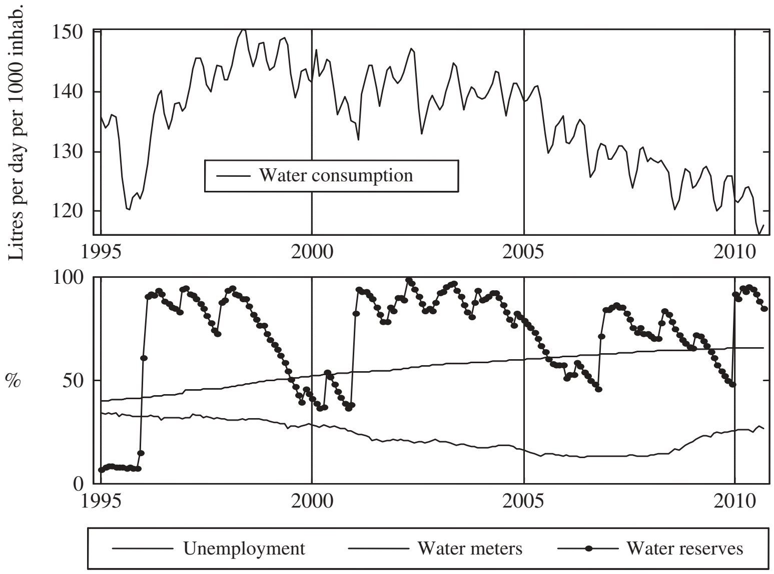

Fig. 1. Upper panel: mean daily water consumption per every 1000 inhabitants in Seville. Lower panel: unemployment, percentage of water meters compared to number of buildings, and percentage of water reserves in the reservoirs that serve Seville

The evolution over time of the main variables can be seen in Fig. 1.

Many facts are apparent at first glance in Fig. 1. Firstly, it is striking that water consumption, which is initially very low, rapidly increases and then falls slowly over the period under consideration. In fact, at the end of the period water consumption is lower than when the sample began. It is evident that initial extremely low consumption was due, above all, to the drought experienced by the city in the 1991–1995 period coinciding with a serious economic crisis. At that time the water supply was systematically cut off and a major change in the consumer habits of the Sevillian people began to be evident. The subsequent rising afterwards enables us to reject any hypothesis that *per se* after a period of water crisis such as major drought, the healthy habits acquired by citizens are maintained. Though this initial effect is quite illustrative of what happens during a period of a great drought, there is a serious distortionary effect due to the fact that it is at the beginning of the sample. This is why the first three years were eliminated from the database.

Secondly, the growing evolution of the percentage of water meters makes one think that this variable is to a large extent responsible for the similarly systematic fall in consumption over the whole period. Finally, at first glance it can be seen that the crisis periods when the amount of the water reserves fell were shorter and less severe the closer we get to the present time.

III. Methodology

The nature of the data – time series that are available for study – and the type of relationship between the variables mean that unobserved components models are very convenient for this purpose. These models allow for the breakdown of a time series into a number of unobserved components, such as a trend, or seasonal and irregular components, with economic meaning. The general formulation of these specifications is included in (1) (see Harvey, 1989 or Castillo-Manzano *et al.,* 2012a, b for a fuller explanation).

$$z_t = T_t + S_t + \mathbf{D}\mathbf{I}_t + v_t \qquad (1)$$

In Equation 1 z_t represents water consumption, T_t is a long-term trend, S_t is a seasonal component, $\mathbf{D}$ is a vector of coefficients that measures the linear relationship with the exogenous variables $\mathbf{I}_t$, and v_t is the irregular component, assumed as a white noise, i.e., an uncorrelated Gaussian noise with zero mean and constant variance.

$$\left\{\begin{array}{lll} \text{Trend :} & \begin{pmatrix} T \\ F \end{pmatrix}_{t+1} = \begin{pmatrix} 1 & 1 \\ 0 & 1 \end{pmatrix}\begin{pmatrix} T \\ F \end{pmatrix}_t + \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\begin{pmatrix} w_0 \\ w_0' \end{pmatrix}_t & \\ \text{Seasonal :} & S_t = \sum_{i=1}^{6} S_{it}\,, & i = 1, 2, \ldots, 6 \\ & \begin{pmatrix} S_i \\ S_i' \end{pmatrix}_{t+1} = \begin{pmatrix} \cos\omega_i & \sin\omega_i \\ -\sin\omega_i & \cos\omega_i \end{pmatrix}\begin{pmatrix} S_i \\ S_i' \end{pmatrix}_t + \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix}\begin{pmatrix} w_i \\ w_i' \end{pmatrix}_t, & \omega_i = \dfrac{2\pi i}{12} \end{array}\right. \qquad (2)$$

Equation 1 is the observation equation of a state-space system, completed with the state or transition equation that reflects the dynamic behaviour of each of the components. The state dynamics of the components are shown in Equation 2.

The dynamic specification of the trend requires an additional variable (F_t), that is the trend slope, and depends on two white noises. The seasonal component is a sum of sinusoidal signals in the fundamental frequency of the annual period (12 observations per year) and its harmonics (6, 4, 3, 2.4 and 2 observations per year). It additionally depends on 12 noises.

The full model of the Equation 1 along with the state corresponding equations is formed by block concatenation of the various systems into one general system that may be estimated by maximum likelihood with the help of well-known recursive algorithms, namely the Kalman Filter and the fixed interval smoothing (see details in Harvey, 1989; Castillo-Manzano *et al.,* 2012a, b, and references therein).

IV. Results

The envisaged model must be consistent with everything that has been expressed up to now. A three-step analysis was performed to clearly see the specific relationship between household water consumption and percentage of water meters:

1. Estimate the relationship between water consumption with all the exogenous variables, but with the water meters variable replaced by a trend.
2. Examination of the relationship between the trend and the water meters variable in isolation.
3. Repeat model in 1 with the trend replaced by the relationship found in 2.

The model in the first step is called ‘Initial Model’ in the second column of Table 1. It can be deduced from Table 1 that there is a set of variables that we considered initially, which are not in fact significant. Additionally, the model is adequate from the statistical point of view (see tests in Table 1).

The initial model also shows us that the drought of 1999–2000 had an initial effect with a 1.4% fall in water consumption which rose to 2.9% in the second half of the period (the effect has been split into two on the basis of statistical criteria). Meanwhile, the changes in the tariff from January 2006 on led to a 1.5% fall in water consumption.

The estimated components resulting from the initial model may be seen in Fig. 2.

Table 1. Results of unobservable components estimations

	Initial model	Final model
Easter	−0.001	
Business	−0.000	
Economic activity	−0.000	
Drought May1999–June 2000	−0.014*	−0.018*
Drought July 2000–December 2000	−0.029*	−0.036*
Drought September 2005–October 2006	0.000	
Drought September 2005–December 2005		−0.025*
Drought August 2009–December 2009	0.002	
Constant		4.934*
Tariff	–0.015**	−0.023*
Water meters		−0.307*
Water meters*Tariff		−1.010*
AO2000.FEB	0.042*	0.043*
Trend, slope	3.36, 0 (×10^{-5})	
Cycle (period, variance)		29.97, 2.51 × 10^{-5}
Seasonal	0.67, 0.003, 0.002, 0.02, 0.003, 0.01 (×10^{-6})	3.45, 0.57, 0.11, 0.03, 0.02, 0.06 (×10^{-7})
Irregular	6.30 (×10^{-8})	1.85 (×10^{-6})
σ^2	5.13 × 10^{-5}	4.92 × 10^{-5}
Schwarz Bayesian Criterion	−9.202	−9.278
Q(12)	8.576	11.00
Q(24)	23.804	18.02
KSL	0.068 (0.123)	0.057 (0.329)
H	0.786 (0.163)	0.966 (0.447)

Notes: σ^2 is residual variance; Q(l) is the Ljung-Box Q self-correlation test with 1 lag; KSL is the Kolmogorov-Smirnov-Lilliefors normality test (*p*-values in brackets); H is a variance ratio homoscedasticity test (*p*-values in brackets). * and ** indicate coefficient significance at 1% and 5% levels, respectively.

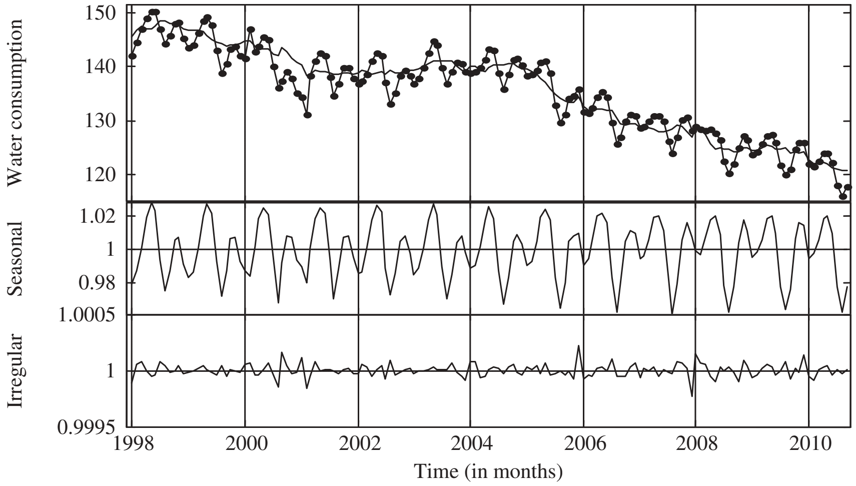

Fig. 2. **Water consumption and unobservable components in *Initial Model*: trend in upper panel, seasonal in middle panel and irregular in bottom panel (break down is logarithmic)**

The second step in the modelling process is to replace the trend with a function of the water meters variable. The relationship between the two can be analysed with a scatter plot between the two variables, as seen in Fig. 3. This figure suggests that a piecewise regression between the trend and water meters would be suitable with the slope changing in January 2006. Three factors with overlapping effects come together at that time in our analysis, namely (i) in July 2005 the area was put on a drought alert that was not brought to an end until October 2006 (see Fig. 1); (ii) from 2006 on the effects of the drought combined with the determined will of the authorities to increase implementation of individual water meters; and (iii) the change in the tariff system philosophy from January 2006 to favour per-inhabitant billing and rationalize water consumption. These two latter factors coinciding in time led us to consider the effect of the July 2005 drought only up to December of that year in the final model, since if it were not taken into consideration a clear step would be left in residuals. In other words, the drought ceases to be relevant for water consumption behaviour from January 2006 as effects come into play that significantly reduced its influence.

A series of additional factors have to be included in the final model in Table 1, which were not envisaged in the original model. The difference between the two is that the initial model trend is replaced by the following components:

(1) A constant that measures the mean level of water consumption for the whole period.
(2) The impact of individual water meters on water consumption measured through its elasticity, modified by the interaction between this variable and tariff changes (the water meters*tariff term in Table 1).
(3) A cyclical component that reflects deviations in the relationship in Fig. 3. Such a term is included as a stochastic sinusoidal cycle like the seasonal component in Equation 2, but with a frequency (or period) that is unknown in principle, and consequently estimated jointly with the noise variance by maximum likelihood.

The model components are shown in Fig. 4.

As the tariff effect is a step variable with a value of 1 from January 2006, the percentage of the impacts that

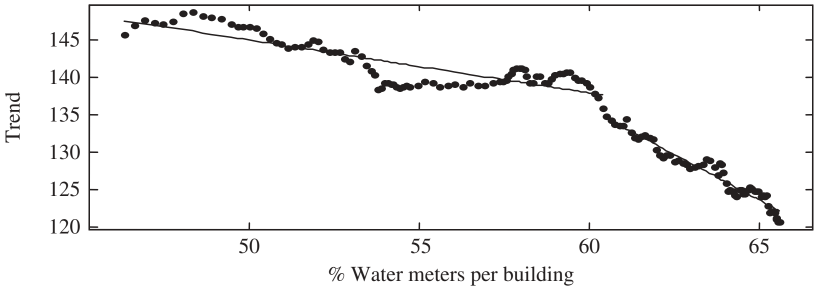

Fig. 3. **Relationship between initial model trend and percentage of water meters per building**

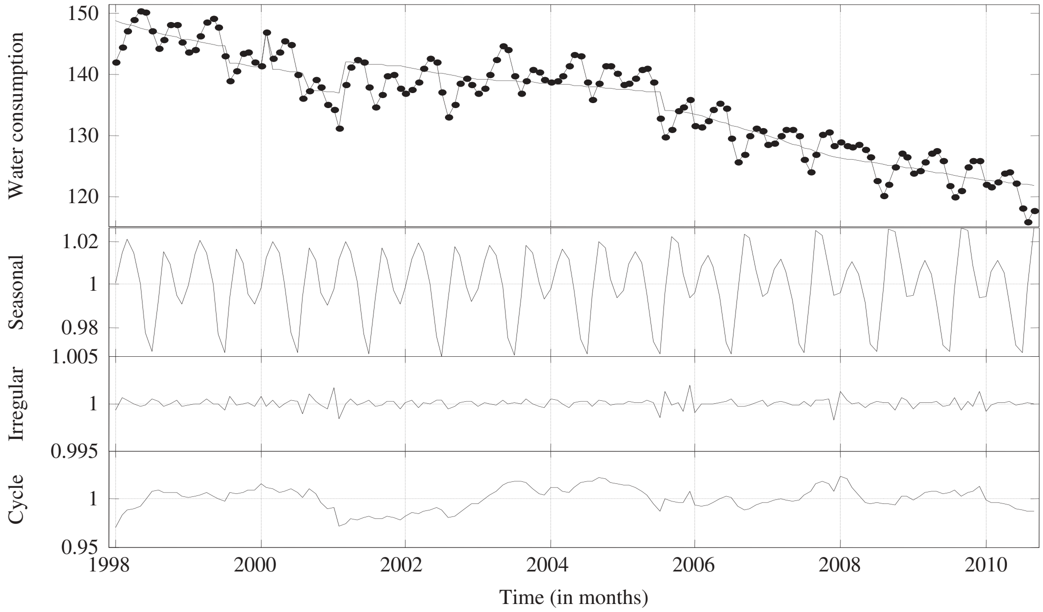

Fig. 4. Components of the final model

begin to be produced on tariffs from 2006 depends on the interaction term, i.e., the overall effect will be $[\exp(-0.023)\mathrm{WA}TERMETERS^{-1.01} - 1] \times 100$. The elasticity of water consumption to the use of individual water meters is –0.307 before 2006, rising (in absolute terms) to –1.317, probably due to the change in the pricing philosophy and the fact that we were in the middle of a drought scenario. In other words, if the water meters variable changes by 1%, water consumption would fall by 1.317%. Although the initial effect is not very large (0.307%), the accumulated effect over the whole period is more significant. To be precise, the 41.71% increase in the ratio of water meters to dwellings during the period (rising from 0.4630 in January 1998 to 0.6561 in September 2010), is what is responsible for the over 37.52% fall in household water consumption during this period. A similar effect in the reduction of water consumption is stated in Nauges and Thomas (2000).

Finally, it must be stated that the marginal effectiveness of implementing individual water meters decreases as 100% implementation is approached, as seen in Fig. 5. The relationship seen in this figure could be a guide to the evolution anticipated for reductions in water consumption as the percentage of water meters per building rises.

V. Conclusions

The main objective of this article is to evaluate the municipal public policy of fomenting a change from communal or banks of water meters to individual or family meters in the city of Seville. Given the broad scope and variety of the databases used, this primary objective can be complemented with a wide range of secondary objectives.

Focusing on periods of less rainfall and, therefore, of greater emergency, it can be concluded that the changes in

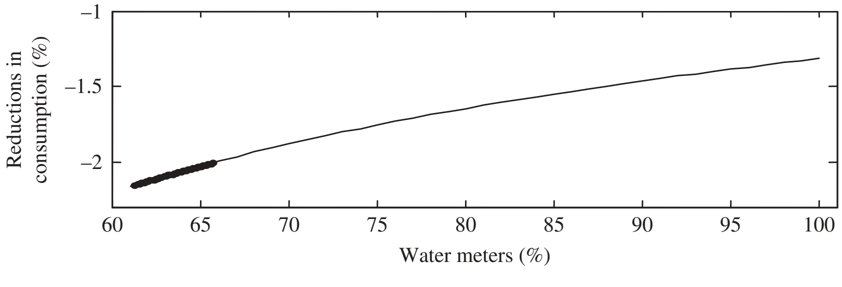

Fig. 5. Relationship between the percentage reduction in water consumption and the progressive implementation of individual water meters as a percentage. The thicker line corresponds to implementation to the end of 2010

habit that Sevillians are forced to make in these circumstances are far from permanent; not even long-term changes can be spoken of. This is confirmed by the fact that the better specification of the variable that shows the effects of the last official drought in 1999–2000 and the more conflictive subsequent situations when water reserves fell below 60% is always in step form. This means that once the crisis is over, the effect is no longer felt at all and the step ceases to exist. Specifically, in the final model the 1999–2000 water crisis is significant in its entirety, the 2005–2006 crisis only during the first months, and the 2009 crisis not at all. This would seem to indicate that two circumstances need to coincide for Sevillians to change their consumption habits. On the one hand, there have to be possible problems with supply and, on the other, there has to be a clear call from the competent authorities, in this case the municipal government, for said habits to change. We therefore believe that it was the June 2005 drought alert and, above all, the official declaration of a drought by the municipal government in 2000 that, in combination with coercive information campaigns to change consumption habits, threatening fines for people who did not effectively reduce their consumption compared to the previous year, brought about a change in habits and not the greater or lesser social awareness of the problem. In fact, the cited step effect for 1999–2000 disappears as soon as the municipal government lifts the proclamation of a drought. In the 2009 crisis, no official drought was declared, which might be justification for it not being significant.

Even so, this none too triumphalist vision of Sevillians' behaviour during times of water crisis should be complemented with the undeniable fact that current per capita domestic consumption is significantly less than the lows that were seen during the last major drought of 1992 to 1995, when reserves fell to an alarming 7% and cuts in the water supply were what obliged falls in consumption. An explanation of this drastic change becomes the primary objective of this article.

In this respect, our study shows that the elasticity of water consumption with individual water meters is significantly negative, although changing throughout the whole period. To be more precise, the situation has gone from one to which there was an inelastic response with an effect that was clearly below 1%, to a response that is a very elastic in recent years. This result is a superb endorsement for these water-meter individualization policies to be continued (as recommended by Nauges and Thomas, 2000), more so when we take into account that any reduction achieved by this means is permanent over time, unlike the reductions that were achieved through coercive measures during drought periods.

It is also striking that the elasticity of consumption to the use of individual water meters has increased significantly in recent years. Part of this greater effect could be due to changes in tariffs that set the consumption limit of the basic block in keeping with the number of registered residents in the household. At first sight it might seem that the only incentive that this principle generates is for people to officially register on the census. However, this article considers that there is a specific segment of the population that this measure has clearly induced to save water. To be precise we would be speaking of households of four members or less. At the beginning of our study period, the top limit of the basic block when there was no proof of the number of residents living in a dwelling was set according to the needs of a four-member household (16 m^3 (3,519,507,973 imperial gallons)/household), and in recent years this has gradually fallen to a limit of 4 m^3 (879,876,993 imperial gallons)/household, i.e., the basic consumption of one person. Households with fewer than four members have therefore gone from having a certain excess amount of consumption covered according to the old basic block, to a situation where any new excess will add to their water bill significantly, as they will soon move out of the bottom block.

To summarize, synergies in water conservation can be seen to exist when both measures – individual water meters and per-inhabitant pricing – have a joint effect. Both these measures promote sustainable consumption habits as they are aimed at making citizens take charge of their own consumption. In other words fairness, one of the basic foundation stones of any economic system, is also the best conservation strategy for guaranteeing the efficient management of our water resources.

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