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Authors	Massimo Pizol (AU) and Maria Molinos Senante (UVEG)
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1. Introduction (cf. Research Plan)

In the context of ex-ante assessment of EPIs, for the study area of Odense River Basin (ORB), the case of an *improved Danish water supply tax on water abstraction* (EPI1) is considered, with the objective of determining (ex-ante) how can water quantity-oriented EPI improve water quality. The approach chosen by AU is hybrid modelling: economic models are combined with hydrological models. The present document addresses and describes the methodology and choices behind the economic modelling. This work has been conducted jointly by Aarhus University (AU) and University of Valencia (UVEG).

2. Objective of the analysis

The main objective is to determine the relationship between price of drinking water and water consumption, on the hypothesis that an increase in water price leads to a decrease in water consumption. Only household users are considered in the analysis. Previous studies [1-3] used regression analysis to determine such relationship, which allows the quantification of the *price elasticity of water demand*. By knowing the value of elasticity, we want to determine the effect that a marginal increase in price will have on the water demand. In particular, the effect of increasing the price with a tax on water abstraction (EPI1) should be estimated in terms of reduced water abstraction, thus giving a measure of the reduced pressure of economy (households) on the natural reservoirs in the basin. This information will feed the hydro-geological model that will determine changes in water quality related to changes in water abstraction.

3. Materials and methods

3.1 Data

Water demand for households is not only influenced by the price of water, but also by several other variables: economic factors as e.g. income, size of the house, presence of water-using appliances; and climatic factors as e.g. temperature and precipitation (in warmer conditions people use more water to wash and to water plants). We couldn't retrieve detailed information at household level for the ORB, only at municipal level and for a time-span of 15 years. The primary data on water consumption and price were provided by *Vandcentersyd* (VCS), the water supplier in Odense (biggest city in the ORB) and are considered as representative for the ORB. Data on income and climate are retrieved from national Danish statistics. The price structure of VCS is the following (Table 1, prices reported for year 2010):

Year	2010
Water variable price [Kr./m3]	5.55
Groundwater fee[1] [Kr./m3]	1.00
Abstraction tax [Kr./m3]	5.00
Wastewater tax [Kr./m3]	21.85
Fixed Water Price [Kr.]	480.00
Fixed Wastewater Price [Kr.]	0.00
VAT (%)	25.00%
Total Variable Price (including taxes and VAT) [Kr./m3]	**41.75**
Total Fixed Price (Including taxes and VAT) [Kr.]	**600.00**

Table 1 water price structure, city of Odense.

It can be seen that the total water price is given by a fixed component, that is the same for each user, and a variable component, that changes according to the amount of water used by each user. The variable price is linear (no block prices).

The details about all the variables examined in the study are reported in table 2.

Variable	**Details and unit**	**Source**
hWS	Water sold to households [m3]	VCS[2]
POP	Users [person]	VCS
hPC	Per capita household water cons. [m3/person]	=hWS/POP
VP	Total variable price [Kr./m3]	VCS
FP	Per capita fixed price [Kr.]	VCS
INC	Income [Kr./person]	DNS[3]
T	Temperature [°C}	DMI[4]
P	Precipitation [mm]	DMI

1 This is basically part of the variable price, but is collected separately and used for green projects (e.g. planting trees)

[2] Vandcentersyd http://www.vandcenter.dk/

[3] Danish National Statistics http://www.dst.dk/

[4] Danish Meteorological institute http://www.dmi.dk

S	Sunshine [hours]	DMI
C	Cloud Cover [%] of total DK surface	DMI

Table 2 primary data acquired for the analysis

Data are given for years 1995-2010. To remove the effect of inflation, the value of the economic variables (prices and income) for each year *t* was deflated to 2010 by using the Danish Consumer Price Index (the Annual Average Index AAI, 2010=100, is available at Danish National Statistics http://www.dst.dk/) according to the following equation 1 (for the case of the variable VP):

$$dfVP_t = \frac{(VP_t \times 100)}{AAI_t} \quad (1)$$

Therefore, three more variables were obtained (table 2) that are corrected for inflation. This allowed us to study time series consistently.

Variable	Details and unit	Source
dfVP	deflated Total variable price [Kr./m3] (2010 = 100)	Eq. 1
dfFP	deflated Per capita fixed price [Kr.] (2010 = 100)	Eq. 1
dfINC	deflated Income [Kr.] (2010 = 100)	Eq. 1

Table 3. deflated variables

Primary data on prices and amount of water sold are not reported in the present memo to follow a specific privacy requirement of VCS. Only aggregated information is provided.

3.2 Statistical approach

The regression analysis method enables to express the relationship between water consumption, the dependent variable, and economic factors (such as the price of water, income, etc.) and climatic ones (temperature, precipitation, percentage of cloud cover), that are independent variables.

The aim of the regression analysis is twofold: (i) Explicit determination of the functional form that relates the variables (prediction) and (ii) compression of the interrelationships between variables involved in the analysis.

The general regression model is as follow:

$$Y = m\,(X_1, X_2, \ldots, X_k) + \varepsilon \quad (2)$$

where:

Y is the independent variable, m is the regression function, $X_1, X_2, \dots, X_k$ are explanatory variables and ε is the model residue (unobserved random variable that adds noise to the model). In our specific case and following previous studies, the linear regression is the one which provides the best adjustment. Hence, given a data set of n statistical units $(Y_i, X_{i1}, X_{i2}, \dots, X_{ik})_{i=1}^{n}$, a linear regression model assumes that the relationship between the dependent variable Y_i and the p-vector of regressors X_i is linear. The model takes the form of:

$$Y_i = \beta_0 + \beta_1 X_{i1} + \beta_2 X_{i2} + \cdots + \beta_k X_{ik} + \varepsilon_i \quad i = 1, \dots, n \tag{3}$$

Where: Y_i is the dependent variable; X_i are the predictor variables; β is a k dimensional parameter vector. $\beta_1, \beta_2 \cdots \beta_k$ are known as regression coefficients. The interpretation of β_k is the expected change in the dependent variable for a one-unit change in X_k when the other dependent variables are held fixed. Moreover, ε_i is the error term that captures all the other factors which influence the dependent variable other than the explanatory variables.

Standard linear regression models make a number of assumptions about the predictor variables, the response variables and their relationship. The following are the major assumptions made in our estimation:

- Independence of errors. This means that the errors of the predictor variables are uncorrelated with each other.
- Homoscedasticity. Different independent variables have the same variance in their errors, regardless of the values of the dependent variables.
- Lack of multicollinearity in the dependent variables. This means that the design matrix X is invertible.
- Weak exogeneity. The dependent variables can be treated as fixed values instead of random variables.
- Linearity. The mean of the independent variable is a linear combination of the parameters (regression coefficients) and the dependent variables.

The linear regression model may be fitted by using several approaches. In our case, as in the majority, it has been fitted using the least squares approach. This means that the overall solution minimizes the sum of the squares of the errors made in the results of every single equation.

The aim is to adjust the parameters of a model function to best fit a data set. A simple data set consists of k points$(Y_1 i, X_1 i)$, $i = 1, \dots, k$ where X_i is the independent variable and Y_i is a dependent variable. The aim is to find the parameter values for the model which best fits the data. The least square method finds its optimum when the sum, S, of the squared residuals is a minimum. A residual, r_i is defined as the difference between the actual variable and the value predicted by the model.

$$S = \sum_{i=1}^{k} r_i^2 \tag{4}$$

$$r_i = Y_i - f(X_i, \beta) \tag{5}$$

Once the regression model has been developed, the next step is to check if all independent variables are significant. The simplest verification is to check that all the regression coefficients, β, have the sign expected from the theoretical point of view. A further step is to carry out a statistical hypothesis test. The null hypothesis is H_0 while the alternative one is H_1 (H_0: $\beta_j = 0$; H_1: $\beta_j \neq 0$).

If the *p-value* is lower than α (in a statistical hypothesis test with a level of significance α) then the null hypothesis is rejected. Hence, with a 95% of significance, the variable can be included in the model.

Regarding the quality of the adjustment, it can be assessed though the coefficient of determination. This coefficient measures the proportion of total variability of the dependent variable relative to its average, which is explained by the regression model. Its value is between 0 and 1. If the determination coefficient value is 1, the adjustment between actual and estimated data is perfect. While, if it takes the value of 0 indicates that there are no relationship between these variables. Considering this scale of values, usually an adjustment is considered acceptable when the determination coefficient value is greater than 0.5, and closer to 1 better will be the quality of adjustment.

4. Results

The dependent variable is *hPC*. We performed different simulations by considering different groups of independent variables (variable price only; variable plus fixed price) different demand functions (linear; log-linear). The first hypothesis is that consumers will respond only to changes in the variable price. Including only variable price, the following regression models (RM) were found, where *dfVP*, *T*, *C*, and *P* variables are significant, whereas *dfINC* and *S* are not.

RM1

$$\boldsymbol{h}PC = 6904{,}034 - 0{,}358\, dfVP + 0{,}866\, T - 70{,}426\, C - 2{,}928\, P$$

$R^2 = 0{,}982$ Significance: dfVP: 0,001; T: 0,011; C: 0,000; P: 0,000

RM2

$$\ln \boldsymbol{h}PC = 134{,}784 - 0{,}210 \ln dfVP + 0{,}019\, T - 1{,}324\, C - 0{,}057\, P$$

$R^2 = 0{,}985$ Significance: dfVP: 0,002; T: 0,006; C: 0,000; P: 0,000

We tried to include fixed price the following models were found where *dfVP*, *dfFP*, *T*, *C*, and *P* variables are significant, whereas *dfINC* and *S* are not.

RM3

$$hPC = 11519{,}794 - 0{,}873\ dfVP + 0{,}018\ dfFP + 0{,}764\ T - 120{,}734\ C - 4{,}634\ P$$

$R^2 = 0{,}991$ Significance: dfVP: 0,000; dfFP: 0,008 T: 0,004; C: 0,000; P: 0,000

RM4

$$\ln hPC = 204{,}616 - 0{,}495 \ln dfVP + 0{,}158 \ln dfFP + 0{,}018\ T - 2{,}085\ C - 0{,}083\ P$$

$R^2 = 0{,}991$ Significance: dfVP: 0,002; dfFP: 0,023 T: 0,002; C: 0,000; P: 0,000

Although *dfFP* is significant in the model, its coefficient has a positive value, i.e. more fixed price means more water consumption. Obviously, this has not sense, and confirms our hypothesis of excluding the variable form the analysis.

Once the formula for the demand function $Q_d = F(P)$(where *Q* is quantity of water and *P* is price) is known, the price elasticity of water demand (intended as the responsiveness of the quantity demanded of water to a change in its price) can be calculated as in equation 6:

$$E_d = \frac{P}{Q_d} \times \frac{dQ_d}{dP_d} \qquad (6)$$

For the case of **RM1**, we found that the point-price elasticity (i.e. the elasticity calculated for each year according to equation 6) E_d is negative and its absolute value is increasing in time: E_d ranges from the value of E_{d_1995} = -0.17 (year 1995) to the value of E_{d_2010} = -0.37 (year 2010), whereas the average elasticity calculated for all 15 years is of E_{d_mean} = -0.28. Therefore, the demand is relatively inelastic. Similar considerations are valid for **RM2**: since the function is of log-log type, the price elasticity calculated with this model is the coefficient $E_d = \beta_1 = -0.21$.

5. Discussion

The results show that the water demand is relatively inelastic for the case of the city of Odense. This means that the percentage change in quantity demanded is less than the percentage change in price. Consumers respond therefore to a change in price by reducing their consumption. Although the results are in the range of elasticity values reported in literature (between -0.05 and 0.75)[4], this response is quite low compared to other cases in the literature [2, 3].

The variable of income resulted non-significant. This was expected as income changes are only due to temporal factors, and the available data are at municipal level and do not reflect the variability in the income of single users. This low resolution of the data may constitute a source of uncertainty, as e.g. factors like the dimension of the house, the use of domestic appliances consuming water, etc., could not be included in the analysis.

The case of Odense is taken as representative for the entire ORB. This is a necessary approximation given the data and time availability. Other drinking water suppliers in the ORB do not apply a linear pricing system, e.g. the second supplier in the area (in terms of size of population supplied) applies a block-price structure. Therefore, the estimate for Odense may not apply for such supplier. Nevertheless, the level of accuracy of the approach here presented is considered as sufficient for the scope of the ex-ante assessment of EPI in ORB, considered that Odense is the main city in the area and that the water abstraction from such city constitutes the largest share of the water abstraction in ORB.

6. Conclusion and perspectives

The study presents a simple model to estimate the elasticity of water demand for the case of ORB. The results show that the demand is relatively inelastic. Such values will be used for the ex-ante assessment by assessing how much water savings can be achieved by increasing the price with an EPI in the form of a tax on water abstraction. Based on this estimate, a hydro-geological model will be used to link such reduction in water abstraction to changes in water quality, to determine whether the EPI has any effect on improving the water quality in the basin.

Based on the present analysis, a feasibility study will be conducted to test the same methodology on a larger database including different water suppliers in Denmark. The database will be in the form of panel-data: time series of coupled data on water consumption and price for several different companies and municipalities in Denmark will be analysed. A preliminary data mining showed that data may be retrieved from several benchmark analyses (e.g. [5]) performed by the Danish water and wastewater association (DANVA) at national level. The objective of this further analysis will be to up-scale the ex-ante assessment from the river basin area to the national scale, and to investigate whether the introduction of the EPI1 will have similar effects on water abstraction, given the price elasticity of water demand at national level.

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