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Measuring consumers' willingness to pay for quality of drinking water using market data:

An application to France during the eighties

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Abstract

Valuation of the costs incurred by consumers due to a decrease in tap water quality would provide valuable insights to policy makers. In this paper, we present and implement a method to infer the value for consumers of the quality of supplied water. Our approach uses concepts developed in the literature of environmental good valuation and the literature of equivalent scale measurement. Our application to French data covering the eighties proves that the approach is tractable: it only uses usually available data and it gives rather intuitive results while relying on reasonable assumptions.

Measuring consumers' willingness to pay for quality of drinking water using market data: An application to France during the eighties

Introduction

During the late eighties questions have arisen about the quality of supplied water in France. It seems that the mass media have originated this by speaking about water pollution by nitrates and pesticides and its potential effects on health.

The main observable implication of this is a dramatic increase in the consumption of bottled water during the eighties (+65% in the *per capita* consumption from 1981 to 1991). This suggests that the French consumers only consider the decrease in the true or presumed quality of tap water when it is used as a beverage. This also reveals that consumers may incur significant costs due to supplied water pollution, the cost of drinking tap water being negligible when compared to the cost of bottled water consumption. A valuation of these costs would provide valuable insights to policy makers, by measuring the benefits associated with an improvement in the quality of supplied water.

In this paper, we propose and implement a method to infer the value of the quality of supplied water when it is used as a beverage. The lack of data we have to face and the nature of the problem we have to deal with preclude direct use of standard methods of environmental goods valuation. Hence, we develop a method that is indirect and that only requires usually available data: purchases and prices of marketed soft drinks for households supplied with variable but identifiable qualities of tap water.

The first section briefly presents our theoretical framework. It is based on two distinct but closely related domains of consumer's economics: public good indirect

valuation and measurement of equivalence scales. The second section presents the data set we used to estimate the value of the quality of tap water for the French young households. The third section presents the empirical model and the fourth section presents the results and their interpretation.

Theoretical framework

Consider a consumer who can consume $K+1$ market goods. The consumed quantities of the goods are denoted by the vector $(x_0, \mathbf{x})$ where good 0 is tap water used as a beverage. The consumer is supplied with water of quality q. The consumers' utility function is denoted by $U(.)$. It is defined over $(x_0, \mathbf{x}, q)$, meaning that the consumer has preferences over the market goods as well as over the quality of tap water. The prices of the goods are denoted by the vector $(p_0, \mathbf{p})$. For an available income y, the consumer's program is defined as:

$$(1) \qquad \underset{x_0,\mathbf{x}}{Max} U(x_0,\mathbf{x},q) \quad s.t. \quad p_0 x_0 + \mathbf{p}\mathbf{x}' \leq y$$

Let $V(.)$, respectively $C(.)$, denote the indirect utility function, respectively the expenditure function, associated with $U(.)$. A relevant measure of the consumer's value of an increase in q from q^0 to q^1 is provided by the compensating variation in income $S(.)$:

$$(2) \qquad S(p_0,\mathbf{p},U^0,q^0,q^1) \equiv C(p_0,\mathbf{p},U^0,q^0) - C(p_0,\mathbf{p},U^0,q^1)$$

where $U^0 \equiv V(p_0,\mathbf{p},y,q^0)$. It corresponds to her willingness to pay for an increase in q, her welfare level being held constant at its initial level U^0.

Different methods may be used to estimate $S(.)$. In a contingent valuation survey, $S(.)$ is elicited by directly questioning to the consumer. This method has already been used in such a context (see, *e.g.*, Crutchfield *et alii*, 1995; Amigues *et alii*, 1995). However, this kind of data is not available in our case.

The other methods are indirect. They rely on some maintained assumptions related to the relationships that exist between q and the observed demands for market goods (Freeman, 1993). Formally, these methods first require to estimate the Marshallian demands $m_k(p_0,\mathbf{p},y,q)$ $(k = 0,1,\ldots,K)$ while explicitly taking into account their variations in q. The estimation of $S(p_0,\mathbf{p},U^0,q^0,q^1)$ then requires to integrate back the expenditure function $C(p_0,\mathbf{p},U^0,q^1)$ or, equivalently, the indirect utility function $V(p_0,\mathbf{p},y,q^1)$. Doing this, one faces a serious identification problem which was clearly exposed by Blundell and Lewbel (1991) in the context of equivalent scales measurement or by Ebert (1998) in the context of public good valuation. The Marshallian demand functions $m_k(p_0,\mathbf{p},y,q)$ completely reveal the consumers' preferences over $(x_0,\mathbf{x})$ given q, i.e. conditional preferences. However, knowledge on the consumers' preference over $(x_0,\mathbf{x},q)$, i.e. unconditional preferences, is necessary to integrate $C(p_0,\mathbf{p},U^0,q^1)$ or $V(p_0,\mathbf{p},y,q^1)$. This follows from the fact that $V(p_0,\mathbf{p},y,q^1)$ is known only up to an increasing transformation that may dependent on q. Hence, without any further information on the consumers' preferences, valuation of q is hopeless.

The standard methods of public good valuation use a result presented by Blundell and Lewbel (1991). This result can be exposed as follows:

Proposition: If there exits a known price regime $(p_0^c,\mathbf{p}^c)$ such that $S(p_0^c,\mathbf{p}^c,U^0,q^0,q^1)$ is known, then the Marshallian demand functions $m_k(.,q^0)$ and $m_k(.,q^1)$ $(k = 0,1,\ldots,K)$ can be used to uniquely recover the true values of $S(.,U^0,q^0,q^1)$ in any other price regime.

In order to apply this result, two main conditions must hold: a price regime $(p_0^c, \mathbf{p}^c)$ such that $S(p_0^c, \mathbf{p}^c, U^0, q^0, q^1)$ is known must be known and this price regime must be identifiable. The focus here is the use value of q as an attribute of tap water used as a beverage. In this context two assumptions appear reasonable: tap water consumption increases in q; and q doesn't matter to a consumer not drinking tap water. Formally this can be written as:

(3a) $\frac{\partial h_0(.,q)}{\partial q} > 0$ if $h_0(.,q) > 0$ and $\frac{\partial h_0(.,q)}{\partial q} = 0$ if $h_0(.,q) = 0$

and:

(3b) $h_0(p_0, \mathbf{p}, U^0, q^0) = h_0(p_0, \mathbf{p}, U^0, q^1) = 0 \quad \Rightarrow \quad S(p_0, \mathbf{p}, U^0, q^0, q^1) = 0$.

The Hicksian tap water demand function $h_0(.)$ being decreasing in p_0, one may find an identifying price regime $(p_0^c, \mathbf{p})$ may be found by simply increasing p_0 up to the point where tap water is not consumed anymore. In this case, tap water and tap water quality are weak complement in Mäler's (1974) sense. However, this result cannot be empirically applied, at least directly, since the drunk tap water quantities are not measured in our data set, as it is usually the case. Thus, it can reasonably be assumed that there exist a price regime where the consumer's willingness to pay is known, but this price regime is not identifiable with our data without further information or assumptions.

The averting expenditure approach (Courant and Porter, 1981) assumes that consumers purchase goods in order to avoid or mitigate the negative effects of q.[1] In our case, the consumers actually face a trade-off: either consuming almost free supplied water despite its bad flavour and health risk, or purchasing expensive but safe beverages

on the market. Considering that bottled water is the closest substitute for tap water and that tap water costs are negligible, one can reasonably assume that:

(3d) $$\frac{\partial h_k(p_0,\mathbf{p},U^0,q)}{\partial p_0}=0 \quad \forall k \quad \text{and} \quad p_0 h_0(p_0,\mathbf{p},U^0,q) << \sum_{k=1}^{K} p_k h_k(p_0,\mathbf{p},U^0,q),$$

(3e) $$\frac{\partial h_1(.,q)}{\partial q}<0 \quad \text{if} \quad h_0(.,q)>0 \quad \text{and} \quad \frac{\partial h_1(.,q)}{\partial q}=0 \quad \text{if} \quad h_0(.,q)=0,$$

(3f) $$\frac{\partial m_1(.,q)}{\partial q}<0 \quad \text{if} \quad m_0(.,q)>0 \quad \text{and} \quad \frac{\partial m_1(.,q)}{\partial q}=0 \quad \text{if} \quad m_0(.,q)=0,$$

and:

(3g) $$\frac{\partial h_0(.,q)}{\partial p_1}>0 \quad \text{if} \quad h_k(.,q)>0, \quad k=0,1 \quad \text{and} \quad \frac{\partial h_0(.,q)}{\partial p_1}=0 \quad \text{if} \quad h_0(.,q)=0$$

where good 1 is bottled water. According to assumption (3g), one may find an identifying price regime $(p_0,\mathbf{p}^c)$ by simply decreasing p_1 down to the point where tap water is not consumed anymore. It can be expected that $p_1^c > p_0$ since it can be considered that the quality of bottled water is always better than the quality of tap water due to its mineral content, its flavour or its image. In this case bottled water and tap water quality are weak substitutes in Feenberg and Mills' (1980) sense. Thus, as previously, one can reasonably assume that there exists a price regime where the consumer's willingness to pay is known. Assumptions (3e)-(3g) ensure that this price regime is identifiable with our data. They ensure that the Hicksian demand of good k conditional on q^1 is equal to the Hicksian of good k conditional on q^0 for any k=1,..,K in a price regime if and only if tap water of quality q^1 or q^0 is not drunk in that price regime:

$$h_0(p_0,\mathbf{p},U^0,q^0)=h_0(p_0,\mathbf{p},U^0,q^1)=0$$

(4a) $$\Leftrightarrow$$

$$h_k(p_0,\mathbf{p},U^0,q^0)=h_k(p_0,\mathbf{p},U^0,q^1),\qquad k=1,\ldots,K$$

and:

$$m_0(p_0,\mathbf{p},y,q^0)=m_0(p_0,\mathbf{p},y,q^1)=0$$

(4b) $$\Leftrightarrow$$

$$m_k(p_0,\mathbf{p},y,q^0)=m_k(p_0,\mathbf{p},y,q^1),\qquad k=1,\ldots,K$$

Condition (4b) can be empirically used to recover p_1^c since it only concerns observed market (Marshallian) demands.

Data

The data that we used consists in six Food Consumption Surveys, one every second year from 1981 to 1991 conducted by INSEE.[2] Each survey provides a random sample of the French population. About 9000 households are surveyed each time.[3] In addition to standard demographic and economic characteristics, these surveys provide specific data on food consumption at a detailed level. We decided to keep only households whose heads are less than 55 years old because older people may have a specific bottled consumption due to health considerations and medical advice.

Having no relevant measure of tap water quality over the studied period, we defined two areas in France by grouping some of the 95 *départements* (French administrative areas) according to our priors on the quality of their supplied water, to geological and topological arguments as well as to the bottled water consumption means per *département*.

We first defined a mountain (M) area, including the main mountains of France: Alpes, Pyrénées, Massif Central, Vosges and Jura. Since supplied water in this area directly comes from preserved springs, tap water quality can be presumed as very good

and constant over the considered period. The average consumption of bottled water of households in this area is low, despite a slight increase in 1991 (1.3 litre/week/household in 1981 and 2.9 litre/week/household in 1991). We then defined a plain (P) area. This area is characterised by a high population density. It concentrates a large part of the French industries. It includes the Large Paris Basin and the eastern part of France (Alsace and Lorraine). It is one of the most fertile area in France where intensive agriculture is common practice since the early sixties. Tap water quality is low at the beginning of the considered period. It might have declined in consumers' minds since. The bottled water mean consumption of households in this area is high during the period (2.5 litre/week/household in 1981 and 4.5 litre/week/household in 1991). The average consumption of elaborated soft drinks is also higher in this area than it is in the mountain area (1.4 litre/week/household in the mountain area against 1.9 litre/week/household in the plain area in 1991). This suggests that bottled water may not be the only substitute for tap water.

In the remaining of the paper, we present the empirical application of our theoretical background with the INSEE data. Specifically our objective is to measure the willingness to pay of households living in the plain area to benefit from the quality of the water supplied in the mountain area.

Empirical implementation

Empirical model

For convenience, it is now assumed that soft drinks form a separable group of goods according to consumers' preferences. Thus $U(.)$ now designs the partial utility of soft drinks, y designs the consumer's soft drink expenditure (where tap water cost is negligible) and the demands of only two market goods are considered (K=2): bottled

water and elaborated soft drinks (juices, sodas, *etc.*). This separability assumption is standard in applied consumption analyses. It is mainly imposed to save degrees of freedom and due to lack of data, but it implies that only partial welfare measures can be recovered. In this context, Hanemann and Morey (1992) showed that the consumer's willingness to pay for an increase in q, when her partial welfare level is held constant at its initial level is always inferior to her willingness to pay for the same increase in q, when her global welfare level is held constant at its initial level. This is because an individual will pay less to bring about an improvement if he is constrained in his ability to take advantage of that improvement, i.e. to change her soft drink utility level in our case.

We assume here that the preferences over soft drinks the considered consumer can be represented by a PIGLOG expenditure function:

(5) $\ln C(p_0,\mathbf{p},q,u) \equiv A(\mathbf{p},q)+I(u,q)B(\mathbf{p},q)$.

According to assumption (4d), p_0 does not appear in the right hand side term of (5). Note, however, that q may influence the cost of reaching utility u through functions $A(.)$, $B(.)$ and $I(.)$. Function $I(.)$ is increasing in its first argument and is introduced to recall that and indirect utility function is known only up to an increasing function that may depend on q. The flexible "Almost Ideal" (AI) forms of Deaton and Muellbauer (1980a) were chosen as parametric forms for $A(.)$ and $B(.)$:

(6) $\ln C(\mathbf{p},q,u) \equiv \alpha_0(q)+\alpha_1(q)\ln z + p_2 + \frac{1}{2}\gamma_{11}(q)(\ln z)^2 + I(u,q)z^{\beta_1(q)}$

where $z \equiv p_1/p_2$. Application of Shephard's lemma leads to the following form for the Hicksian and Marshallian share of bottled water in soft drink expenditure:

(7a) $s(\mathbf{p},q,u) = \alpha_1(q)+\gamma_{11}(q)\ln z + I(u,q)\beta_1(q)z^{\beta_1(q)}$

and:

$$w(\mathbf{p},q,y)=\alpha_1(q)+\gamma_{11}(q)\ln z + \beta_1(q)\left[\ln\left(\frac{y}{p_2}\right)-\left(\alpha_0(q)+\alpha_1(q)\ln z+\frac{1}{2}\gamma_{11}(q)(\ln z)^2\right)\right] \tag{7b}$$

All parameters of (6) can be estimated from price and consumption data for goods 1 and 2. Thus the identification problem of (6) is only associated to $I(.,q)$. The $I(u,q)$ values only characterise indifference curves associated to the consumer's preferences in the **x** space, q being given. They cannot directly be compared for different q's.

If p_1^c is the price under which tap water consumption is choked off and $\mathbf{p}^c=(p_1^c,p_2)$, we have:

$$\ln C(\mathbf{p},q^1,U^0)=A(\mathbf{p},q^1)+\frac{B(\mathbf{p},q^1)}{B(\mathbf{p}^c,q^1)}\left[A(\mathbf{p}^c,q^0)-A(\mathbf{p}^c,q^0)\right] + \frac{B(\mathbf{p},q^1)}{B(\mathbf{p}^c,q^1)}\frac{B(\mathbf{p}^c,q^0)}{B(\mathbf{p},q^0)}\left[\ln y-A(\mathbf{p},q^0)\right] \tag{8a}$$

and:

$$S(p_0,\mathbf{p},U^0,q^0,q^1)\equiv y-C(p_0,\mathbf{p},U^0,q^1). \tag{8b}$$

Note that $\mathbf{p}^c$ identifies $S(.)$ since both expressions (8a) and (8b) only depend on empirically estimable parameters or known variables.

Using conditions (4), one can recover p_1^c as the highest value for p_1 (below its actual level) satisfying the following equation:

$$w(\mathbf{p}^c,C(\mathbf{p}^c,U^0,q^0),q^0)-w(\mathbf{p}^c,C(\mathbf{p}^c,U^0,q^0),q^1)=0 \tag{9a}$$

where:

$$C(\mathbf{p}^c,q^0,U^0)=A(\mathbf{p}^c,q^0)+B(\mathbf{p}^c,q^0)\frac{\left(\ln y-A(\mathbf{p},q^0)\right)}{B(\mathbf{p},q^0)} = A(\mathbf{p}^c,q^0)+B(\mathbf{p}^c,q^0)I(U^0,q) \tag{9b}$$

The first left hand side term of (10a) is the Hicksian share of bottled water in soft drink expenditures in the price regime $\mathbf{p}^c$: $s(\mathbf{p}^c, U^0, q^0)$. According to (4), the left hand side term of (9a) is positive for prices of bottled water superior to p_1^c. Consumers supplied with low quality tap water purchase more bottled water than consumers supplied with high quality tap water. At this point, it should be noted that the bottled water price that chokes off tap water demand is very different from the actual bottled water price. Thus, the estimated p_1^c must be used with caution since it is determined by using the estimated demands out of the domain where they can be considered as good approximations of the true ones.

Econometric model and estimation procedure

In the Food Consumption Surveys, households are surveyed during only one week. Thus, at the individual household level, relevant econometric models would need to take into account infrequency of purchase, corner solutions and truncation features. A way to avoid these problems is to work with data aggregated over households. We used a simple aggregation procedure. Thanks to the large number of surveyed households, we defined 7 cohorts of six-years age band and aggregated the households of these cohorts as "representative aggregated households" in each survey.[4,5] For example, households whose head was born during the 1944-1950 period were aggregated in each survey thus forming a representative household whose head was approximately 34 years old in 1981, 36 years old in 1983, *etc.* The bottled water budget share (w) of a "representative household" at time t is the share of the total expenditure on bottled water in the total expenditure of soft drink of the considered cohort at time t. The total expenditure on soft drinks (y) of an "aggregated representative households" is deflated

by the number of represented households. The price variables are the standard prices indices computed at the country level by INSEE.

Having no indicator of the quality of tap water during the studied period, we estimated a demand function for bottled water for each of the two defined area. Formally, we estimated budget shares of bottled water of the form:

$$(10a) \quad w_{rct} = \alpha_{1,rct} + \gamma_{11,r} \ln z_t + \beta_{1,r}\left[\ln\left(\frac{y_{rct}}{p_{2,t}}\right) - \left(\alpha_{0,rt} + \alpha_{1,rct} \ln z_t + \frac{1}{2}\gamma_{11}(\ln z_t)^2\right)\right] + e_{rct},$$

where:

$$(10b) \quad \alpha_{1,rct} = \alpha_{10r} + \alpha_{11r} \ln a_{rct}.$$

Sub-index t indicates time (t = 81,...,91), c indicates cohort (c = 1,...,7) and r indicates area (r = m,p). The natural logarithm of the "representative household" average age ($\ln a_{ct}$) is introduced in the parameter α_1 to take into account the positive effect of age on budget share of bottled water. Our structural change tests led us to accept the hypotheses of no structural change for both areas. This would indicate that soft drink demands were not affected by structural changes or were affected similarly by some unknown factors.

It is well-known that with a limited price variation, the practical identification of α_{10r} and α_{0r} is problematical. The usual solution is to impose constraints on either α_{10r} or α_{0r}. (Deaton and Muellbauer, 1980a). Here we chose to impose a constraint on α_{0r}.[6] This parameter can be interpreted as the natural logarithm of the minimal outlay required for a minimal standard of living ($I(u,q)=0$) when prices indices are unity (Deaton and Muellbauer, 1980a). Here we impose the condition that if the price of bottled water is equal to 15% of its actual level, then the minimal outlay (deflated by p_2)

is equal to about 20% of the minimal observed outlay (deflated by p_2). Estimates then showed that the hypotheses that the parameters α_{10r} and α_{11r} are equal for both areas could be accepted. This result implies that, according to our assumptions, when the price of bottled is low, similar households supplied with different water quality can have identical soft drink demands, i.e. can reach the same (minimal) utility level. The equality constraints on the α_{10r} and α_{11r} parameters were imposed to increase estimation efficiency and to save degrees of freedom.

We used the two stage non-linear least squares estimator to account for the endogeneity of the soft drink expenditure variable (y). The average total income of the cohort was used as an instrumental variable in addition to the price and age variables (and their combinations in w) that can be assumed exogenous. The error terms e_{rct} are assumed to be independent and identically distributed.

Results

The estimated elasticities of the demands of soft drinks are presented in Table 1. In both areas bottled water appears as a necessity good (within the soft drinks group). However, the estimated elasticity of bottled water demand with respect to the expenditure of soft drinks is lower on average in the plain area (0.75) than in the mountain area (0.93). Similarly the own price Hicksian elasticity of bottled water demand is higher on average in the plain area (-0.17) than in the mountain area. Bottled water, the closest substitute for tap water, has a more rigid demand in the plain area. This could be interpreted as reflecting the fact that tap water is less consumed in the plain area than in the mountain area, according to the Le Chatelier principle applied in the case of consumer behaviour under rationing (Deaton and Muellbauer, 1980b).

Table 1. Means of different elasticities of the bottled water demand in the two considered areas

	Mountain area	Plain area
Mean of the elasticities of the bottled water demand with respect to:		
Soft drink expenditure elasticity	0.93	0.75
Marshallian own price elasticity	-0.75	-0.52
Hicksian own price elasticity	-0.36	-0.17

The estimated prices of bottled water that would choke off tap water consumption appear significantly higher after 1988 than before. Before 1988, a cut in the price of bottled water ranging from 59% to 72% is needed to choke off the Hicksian demand of tap water while a price cut ranging from 41% to 45% is sufficient after 1988. This may be explained by the decrease in the value added tax of soft drinks from 18.6% to 5.5% decided by the French government in 1989.

The estimated willingness to pay of households living in the plain area to benefit from the quality of the water supplied in the mountain is almost null during the whole period. This means that households living in the mountain area would have to spend the same amount in soft drink purchases to reach the actual soft drink utility level of similar households living in the plain area. Households living in the plain area spend on soft drinks about twice as much as households living in the mountain area. Together with our almost null willingness to pay for an increase in tap water quality this indicates that the actual soft drink utility level of households living in the plain area is higher than the actual soft drink utility level of similar households living in the mountain area. In fact, it seems that households living in the plain area are led to purchase bottled water, a good that is considered as almost a luxury in the mountain area, because they want to drink less tap water of low quality. This may explain why they reach a higher partial utility level. People living in the plain area would also find that bottled water is a luxury if they were supplied with high quality tap water. Purchasing bottled water they

purchase safe water, minerals, diet properties, bottles, an advertised image, *etc* while many of them would like to only purchase safe water.[7] In fact, their situation can be compared to that of a man who would like to buy a small cheap car but who is constrained to buy a Rolls Royce because there is no other car on sale in the place where he lives. The considered man buys the Rolls Royce because he needs a car. He surely gets more satisfaction driving his Rolls Royce than driving any other car. But he would have preferred to buy the small cheap car to be able to purchase something he finds more useful than driving a Rolls Royce.

Concluding comments

Our approach uses concepts developed in two apparently distinct literatures: environmental good valuation and equivalent scale measurement. Our application with French data proves that its tractability, in the sense that it only uses usually available data and in the sense it gives rather intuitive results while relying on reasonable assumptions.

Our results provide an argument in favour of Hanemann and Morey's (1992) pessimistic view concerning the usefulness of partial welfare measurement. They show that the lower bound of households' willingness to pay for an increase in tap water quality is close to zero.

However, our results must be interpreted with caution, as we had to estimate simple demand functions as well as to use aggregated data due to data constraints.

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[1] This approach has been used to value drinking water quality by Abdalla *et alii* (1992) and Rosado (1998).

[2] *Institut National de la Statistique et des Etudes Economiques.*

[3] Except in 1989 when only 3000 households were surveyed

[4] We eliminated the "aggregated representative households" that represent less than 100 households. This gave us 31 households *per* area.

[5] A similar procedure is used for the construction of pseudo-panels (Deaton, 1985).

[6] Different tries showed that our results are not sensitive with respect to these constraints. In fact, the choice a value for this parameter simply corresponds to a choice of the scaling of the utility levels related to the households conditional preferences.

[7] The substitution of bottled spring water consumption for the bottled mineral water consumption during the nineties tends to provide another argument in favour of this interpretation of our results (Carpentier and Vermersch, 1998). Bottled spring water is only bottled safe water, it is far cheaper than bottled mineral water and its supply by supermarket chains is growing.