Measuring willingness to pay for drinking water quality using the econometrics of equivalence scales

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Introduction

A safe, reliable and inexpensive drinking water supply is one of the easiest aspects of life in developed countries to take for granted. Yet, water supplies can and do provide water of variable quality. During the late eighties and more accurately during the early nineties, questions about supplied water quality arose in France. Firstly originated by miscellaneous publications of supplied water test results giving serious cause for concern with respect to public health, these questions recently became matter of urgent political decisions. In 1996, a consumers' organization of Guingamp (Bretagne) brought lawsuits against one of the major water companies for having supplied water over 50 mg of nitrates per liter, the legal concentration threshold. The organization won the case and the producer had to reimburse customers for extra cost as they had to purchase bottled water. Moreover, the water company is now suing the French government who did not enforce a relevant policy to abate water pollution by agriculture. The water company argues that land water is common property resource whereas farmers are implicitly entitled with the right to abuse the environment.
This case, along with the dramatic increase in bottled water consumption observed in France since the early eighties, is now originating a social debate with respect to property right entitlement and the safety of water supply sources.

Thank to the generalization of water treatment against bacteriological and fungi contamination, the quality of supplied water may only be questionable in some parts of France for chemical reasons. These problems are mainly due to excessive concentration of mineral components. French households do not purchase private treatment means such as filters[1] and seem circumvent the problems of supplied water quality they face by purchasing bottled water and, perhaps in some cases, other soft drinks. Thus, apart from the property right issue that

[1] However, in regions with highly chalky grounds, some households have got softeners.

may generate a nonuse for the of water resources, the French consumers seem to mainly attribute a value to the supplied water quality when tap water is used as a beverage.

The dramatic increase in bottled water consumption during the eighties thus suggests a decrease in water quality in France, at least in consumers' minds (Figure 1). This decrease in the true or presumed quality of supplied water must be proved and its cost for the French consumers assessed to provide insights to policy makers[2]. More specifically, economic assessments of the costs incurred by households presumably supplied with low quality water are necessary and still to perform. These are the objectives of this study.

We propose and implement a method to infer the value of supplied water quality when tap water is used as beverage. This inference method is indirect and is based on the observation of the French households' soft drink demand.

The lack of data we have to face and the nature of the question we have to deal with preclude direct use of the standard methods of environmental goods valuation: the averting expenditure approach originated by Courant and Porter (1981) and the "public good as quality characteristic of a privately consumed good" originated by Mäler (1974).

Also, in the first part of this paper, we develop a theoretical framework that is adapted to our objectives and data. In fact, our framework exploits concepts used in both approaches. As any indirect method of public good measurement, it relies on some maintained assumptions related to the relationships between the good to be valued and the observed market good demands (Freeman, 1993). We explicitly present these assumptions and argue their

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[2] If this hypothesis was true, it would have important policy implications. Quality improvement policies would be needed in the case of a true decrease in supplied water quality whereas information policies would be warranted in the case of a decrease in supplied water quality only in consumers' minds. See, e. g., Smith *et alii* (1995) and Chern *et alii* (1995) for studies of the effects of information on consumers' mitigating behavior.

plausibility. A crucial point for the use of indirect valuation methods is the existence of particular situation where the quantity or the quality public good to be valued does not affect consumer's behavior. In theory, the valuation question is generally solved by analytical or numerical (see Vartia, 1983) integration of Hicksian demands to obtain the expenditure functions that allow welfare comparisons. However, Hicksian demands generally can't be recovered from observed data. Observed data only allow estimation of Marshallian demands not Hicksian demands. Hausman (1981) shows that Marshallian demands can be integrated back to obtain a quasi-expenditure function that identifies the expenditure function up to a constant of integration. The situation where the quantity or the quality of the public good to be valued does not affect consumer's welfare is used to solve the problem of the constant of integration (Freeman, 1993). We show that our model provide strong arguments in favor of the existence of a price regime where such a situation occurs.

In the second part, we present the econometric model and the procedure used to implement our approach. Provided that our model rests on many unobservable variables, we can't specify a structural econometric model that embodies all the features of the theoretical model, as it is usually done to recover public good values (Larson, 1991 and 1992). In order to overcome this problem, we use the analogy that exists between the estimation of public good values and that of equivalence scales (Blundell and Lewbel, 1991; Pollack, 1991). Estimation of equivalence scales, e.g. in order to estimate child cost, has received considerable attention in the applied economics literature (see, e.g., Blundell *et alii*, 1993; Blundell and Lewbel, 1991). It generally relies on the estimation of a demand system model is that is explicitly derived from a parametric cost function. As recalled above, estimation of the parameters of Marshallian demands only allows recovery of a subset of the initial expenditure function parameters. As noted by Blundell and Lewbel (1991), this identification problem is generally solved by imposing severe restrictions on households' preferences in the studies dealing with equivalence scales. In fact, in our case, the existence of a price regime where the quantity or the quality of the public good to be valued does not affect consumer's welfare allows to solve this identification problem without further restrictions on households' preferences. We propose two simple methods that allows estimation of this price regime by use of estimated Marshallian demands and, consequently, that allow recovery of the whole set of expenditure function parameters. Due to data constraints and for simplicity, we use a version of Deaton and Muellbauer's (1980a, 1980b) Almost Ideal Demand System (AIDS) model. This model is extensively used and seems to perform well for computing equivalence scales (See, e.g., Blundell *et alii*, 1993; Blundell and Lewbel, 1991).

In a third part, we present our data set and the approach that we use to handle the inconvenient originated by the lack of data about tap water quality. Once again, our study needs to rely on maintained assumptions that we explicitly present and argue.

Results are presented and commented in the fourth part.

1. Theoretical framework

As described above and from the consumers' viewpoint, the eventual deterioration of supplied water quality in France may have mainly influenced the properties of tap water when it is used as a beverage. We thus focus our study on the estimation of the use value of supplied water quality[3] and only consider a single use of this quality, its use as a complement of drunk tap water. As a result, we neglect the value of the effects of this quality when supplied water is used in the bathroom, in the swimming pool, to wash the dishes, ..., i.e. the other uses that may originate ingestion of small quantities of supplied water by the consumer. It can be argued that this value should be very closed to zero since it not recommended to wash fruit and vegetables to be eaten without preparation with bottled water, not yet! Following the same logic, we exclude the use of tap water as an input in the production of cooked meals, tea or coffee. It can be noted that this assumption seems reasonable since households do not purchase bottled water for this uses implying that they give no use value to the tap water quality in such cases. Nevertheless, this attitude may be somewhat questionable since the pollutants found in the French supplied water are mainly mineral elements. Many of these elements may not be affected by the boiling process implied in the production of cooked meals such as soups or of coffee[4]. We also exclude the value associated to the effect of supplied water quality on the

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[3] It can be argued here that supplied water quality has only use value, by definition. However, since the French consumers seem to consider that they possess the property rights of the water resources, they may have a non null nonuse value for the supplied water quality. Anyway, the only known method for estimating nonuse values of quality changes rely on the integration of some function of the marginal effects of the considered quality on the Marshallian demand of some chosen market goods (Neill, 1988; Larson, 1992; Flores, 1996). The lack of data related to supplied water quality in France precludes estimation of this marginal effects.

[4] It also can be noted that the recommendations provided in the case of contamination incident such as an excessive concentration of nitrates mention to not drink the concerned supplied water (at least for young children and older persons) but never mention to not use it as a cooking ingredient.

households' equipment maintenance. To a very large extend these problems are originated by hard water, i.e. by a permanent characteristic of the water supplied in chalky areas, a sort of problem traditionally out of the scope of public intervention.

As almost every environmental good, tap water quality is a non-market good and consequently a good whose economic value is implicit. Thus, apart from costly and "*in vitro*" contingent valuation methods, only indirect methods remain available to value supplied water quality (Freeman, 1993; Mitchell and Carson, 1989). These methods are generally based on some hypothesized relationship between the observable demand for marketed goods and the unobservable demand for public services or goods.

Within this context, one of the most popular inference strategy treats the public good to be valued as a characteristic of a market good whose demand is observable (Bockstael and McConnell, 1993)[5]. Supplied water quality can obviously be interpreted as a characteristic of tap water. In this case, the most appealing strategy is to consider that the public good and the market good are linked *via* a specific relationship labeled by Mäler (1974) as weak complementarity (Bockstael and McConnell, 1993) or its generalization: the weak Hicks neutrality of Larson (1992)[6]. However, as the eventual deterioration of supplied water quality in France may have mainly influenced the properties of tap water when it is used as a beverage,

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[5] Indeed Bockstael and McConnell (1993) use an household production framework (See also Bockstael and McConnell, 1983 and Bockstael and Kling, 1988). They argue that, by using the public good (supplied water quality) and market goods (purchased tap water) an household produce non-market private good (drinking tap water). Here, we consider drunk tap water as both the purchased and consumed good since the distinction is not really needed. In other cases, this distinction may be useful. For example, the combination of a lake with fishes (the public good to be valued) , trip costs and fishing equipment (the market goods) enables an household to produce fishing activities (the non market-good).

[6] In fact, Larson (1992) first defined his weak Hicks neutrality concept as a generalization of Neill's (1988) enlightening but rather unrealistic Hicks neutrality concept. See also Flores (1996).

we face a serious lack of data. The consumed quantities of tap water that are drunk by households, i.e. what can be considered as the only market good that has a direct relationship with supplied water quality, is generally unknown. Given that the part that is used as a beverage in the households' total consumption of supplied water is very small, trying to infer the value of the quality of supplied water by studying the global demand of supplied water is hopeless. Thus, in our case, the value of tap water quality must be inferred from the observation of the demand market good for which the public good can not be considered as a quality characteristic. Unfortunately and as noted by Larson (1991) and Bockstael and McConnell (1993), for cases where the structure provided by weak complementarity (or weak Hicks neutrality), there is not much guidance about alternative structure that would enable the measurement of welfare changes due to quality changes.

In our case, however, another strategy to value environmental goods may be used. Along the line of Courant and Porter (1981), it seems natural to interpret households' bottled water expenditures as averting expenditures. Where quality is (perceived as) low, the concerned households are facing a trade-off: either consuming the supplied low quality water, risking illness and/or sustaining some degree of disutility due to bad taste thereby, or incurring costs in order to improve the supplied water quality or to purchase drinking water from other sources. Where the trade-off is well defined and its determinant parameters of variable well identified, it is possible to use a model derived within an household production framework to assess the benefits of a change in the considered public good (Harrington and Portney, 1987; Shibata and Winrich, 1983; Harford, 1984). In the case of supplied water quality, Harrington *et alii* (1989), Abdalla *et alii* (1992) and Laughland *et alii* (1993) used a cost of illness approach to value the cost associated with a groundwater contamination incident in

Pennsylvania[7]. Two main problems are associated with the application of the standard averting expenditure approach. The first one is that it requires an explicit specification of the trade-off faced by the considered households. In order to directly use this approach, we would have to specify the effects of the supplied water quality on households' utility. Apart from the taste effects, we would have to specify the effects of the drunk tap water quality on consumers' health. More exactly, since these effects are not well defined, we would have to specify these effects as they are expected by the households. Even if progress have been done in this area (see, e. g., Chern *et alii*, 1995), use of this approach remains difficult. The second problem associated with the averting expenditure approach is concerned with the existing link between the public good to be valued and the good that is used to avert its effects. In order to specify a tractable model we would have to assume that bottled water is only used to avoid consumption of tap water (Freeman, 1993; Smith, 1991). Several facts lead us to cast serious doubt on such an assumption. Firstly, consumption of mineral water may be warranted by doctors for medical reasons (specifically for old people and young children). Secondly, bottled water producers advertise their product by presenting it as a diet product[8]. Finally, and perhaps more importantly, bottled water is consumed all over France, even in areas supplied by sources that also supply mineral bottled water producers!

Because we can't directly use any of the standard indirect valuation methods presented, we develop a specific framework. In fact, our framework exploits concepts used in both of the methods presented above. As any other valuation method using an indirect approach, our

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[7] Other applications of this approach may be found in Murdoch and Thayer (1990); Joyce, Grossman and Goldman (1989); Gerking and Stanley (1986) and Watson and Jaksh (1982) among others.

[8] During the eighties, mineral water represented more than 80% (in volume) of the market of flat bottled water in France.

method relies on some hypothesized relationships between the observed demands for market goods and the unobservable demands for environmental goods. These relationships are generally assumed *a priori*. In our case, the demand for the only market good that has a direct relationship with the public good to be valued is not observed. Thus, we must be very careful in defining the assumed relationship upon which our entire analysis will rely.

If one can easily have strong intuition about the effects of the public good on Marshallian or ordinary demands[9], *a priori* imposing some patterns on Hicksian demands, as it usually done, seems more difficult since those demands are mainly defined as an analysis tool. Contrary to other studies, our approach involves two steps.

The objective of the first one is to precisely define and compare the characteristics of tap water, of bottled water and of the other soft drinks as well as the characteristics of tap water quality using ordinal concepts, i.e. mainly marginal of substitution. These concepts have the advantage of being more intuitive and, thus easier to check *a priori*, than patterns of Hicksian demands[10]. Comparative statics defined on marginal rates of substitution only involves two or three goods whereas comparative statics defined on Hicksian demands involves the whole set of goods.

In the second step, the implications of these characteristics on the patterns of the Hicksian demands are derived. We argue that this approach is necessary in our case since the lack of data related to tap water consumption we face renders our assumptions even more difficult to check than those imposed in the other previous studies related to this topic. It can be noted that Bockstael and McConnell (1993) provide some arguments in favor of this approach without pursuing it very far.

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[9] If one do not omit the income effects.

[10] Nevertheless, it remains that the characteristics of the considered goods will only help to define other maintained assumptions.

The model

Given the focus of the study and in order to circumvent some empirical problems to be described below, we assume that consumers have the following separable structure:

(1) $F(x_1, x_2, z, \mathbf{q}, \mathbf{G}) \equiv F(U(x_1, x_2, z, \mathbf{q}), \mathbf{G})$

x_1 represents the consumed quantity of bottled water, x_2 that of an aggregate of the other standard soft drinks and z that of drinking tap water. $\mathbf{q} \equiv (q_a , q_b)'$ is a vector of quality indicators of supplied water and $\mathbf{q} \in [\mathbf{q}_{min}, \mathbf{q}_{max}]$. q_a is an indicator of taste quality and q_b an indicator of fitness to drink. As such, $\mathbf{q}$ only represents the properties of supplied water where it is used as a beverage. $\mathbf{G}$ is a vector of quantities of the other market goods.

From a theoretical viewpoint, only considering the quantity of supplied water that is drunk by the household requires a latent separability assumption (Blundell and Robin, 1995). That is we assume that the part of purchased supplied water used as drinking water can be considered as a single (latent) good and that its demand can be analyzed independently with respect to the other parts of the total purchased supplied water. The definition of the partial utility *U(.)* requires the assumption that bottled water, the other soft drinks, tap water and the effects of tap water quality are weakly separable from the other goods in consumers' preferences. The weak separability assumption of groups of good sharing some characteristics is now standard in applied demand economics (Hanemann and Morey, 1992; LaFrance and Hanemann, 1989). But the separability assumption of the tap water quality effects deserves some comments.

When considering the quality indicator related to the flavor of tap water, the separability assumption seems natural. Finding a good that affects the marginal rates of substitutions of the marketed soft drinks for tap water for taste reasons is unlikely. But, purchase of medical care may affect the marginal rates of substitutions of the market soft drinks for tap water. A consumer could drink tap water and not purchase bottled water because he expects that in case of illness he will be able to purchase medical care and appropriate medicine[11]. It is difficult to *a priori* assess the effects of maintaining this separability assumption. On the one hand, the French state provides a compulsory health insurance coverage to the population. This situation may generates "moral hazard like" patterns, in the sense that this insurance coverage can reduce incentives to avert the adverse effects of tap water consumption. In this case, maintaining the separability assumption would imply an underestimation of the value of the degradation of the supplied water quality due to the quasi-gratuity of medical care[12]. On the other hand, these effects may also be limited since the uncertainty related to the health effects of the contamination of the supplied water remains considerable. Neither the potential effects on health of consumption of many water pollutants, and consequently, nor the appropriate medicine to treat them are well known yet. Moreover, monetary payments do not avoid the disutility caused by illness or potential irreversible effects such as sterility. Hence, a consumer exhibiting some degree of risk aversion or prudence may choose to not drink tap water as soon as he becomes aware of this considerable uncertainty.

To keep our focus on the value of supplied water quality as a complement of drunk tap water, we only consider the cost minimization problem associated with the partial utility *U(.)*, i.e., the soft drink utility:

(2a) $$\underset{x_1,x_2,z}{Min}\; p_1 x_1 + p_2 x_2 \quad s.t. \quad U(x_1, x_2, z, \mathbf{q}) \geq \overline{U}\,.$$

It is the dual of the standard partial maximization problem:

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[11] He may also expect that consumption of appropriate food builds sufficient resistance with respect to the eventual adverse effects of tap water consumption. However, this case *a priori* seems unlikely.

[12] Any other method of inference of consumers' willingness to pay would face the same problem.

(2b) $\underset{x_1,x_2,z}{Max}\, U(x_1,x_2,z,\mathbf{q}) \quad s.t. \quad y \geq p_1x_1 + p_2x_2$

where p_i is the unit price (index) of good i, $\overline{U}$ is an arbitrary level of $U(.)$ and y the expenditure level allocated by the consumer for soft drink purchases. Given that the price of its closest (and currently consumed) substitutes are *50* times (spring water) to *100* times more expensive than it is, it can safely be assumed that the price of supplied water can't explain its level of consumption as a beverage, i.e. that tap water expenditures are negligible in the programs (2a) and (2b). Hence, we assume here that the price of tap water is null. In addition to assuming that $U(.)$ and its derivatives are continuous and differentiable as needed, we assume here that:

(3a) $U(.)$ is strictly increasing and strictly quasi-concave in (x_1, x_2) at any level of $(\mathbf{q}, z)$.

This is a standard assumption that ensures the existence and the uniqueness of the solutions to (2) in (x_1, x_2). We also assume that:

(3b) $U(.)$ admits a unique maximum in z and is strictly concave in z at any level of $(x_1, x_2, \mathbf{q})$ where $U_z(.)$, the partial derivative of $U(.)$ in z, is null.

And finally, we assume that:

(3c) $U(.)$ is strictly increasing in $\mathbf{q}$ at any level of (x_1, x_2, z) where $z \neq 0$ and is constant in $\mathbf{q}$ at any level of (x_1, x_2, z) where $z = 0$.

Assumption (3b) implies that when $\mathbf{q}$ is not maximum (i.e. tap water is safe and has no bad taste), the consumer faces an implicit trade-off between the desirable effects of tap water consumption (thirst-quenching) and its undesirable effects (bad taste and potential health state deterioration). This assumption is consistent with the models developed within the standard averting expenditure framework. Where $\mathbf{q}$ is maximum, assuming that $U(.)$ admits a maximum in z relies on a satiation effect. The assumption that $\mathbf{q}$ has no effect on utility when tap water is not consumed is crucial for the definition of conditions that allow identification of expenditure function parameters. But it is consistent with our focus on estimation of use values.

These assumptions ensure that the solutions of (2a), respectively (2b), i.e. the Hicksian demands associated to the partial utility level $\overline{U}$, respectively Marshallian demands associated to the expenditure level y, exist and are unique[13]. These are written as: $h_i\ (p_1, p_2, \mathbf{q}, \overline{U})$ and $h_z\ (p_1, p_2, \mathbf{q}, \overline{U})$, respectively: $m_i\ (p_1, p_2, \mathbf{q}, y)$ and $m_z\ (p_1, p_2, \mathbf{q}, y)$. They are derived from the following Lagrangian functions maximization programs:

(4a) $$\underset{x_1,x_2,z}{Max} - (p_1x_1 + p_2x_2) + \mu\left(U(x_1, x_2, z, \mathbf{q}) - \overline{U}\right)$$

respectively:

(4b) $$\underset{x_1,x_2,z}{Max}\ U(x_1, x_2, z, \mathbf{q}) + \lambda\left(y - p_1x_1 + p_2x_2\right).$$

Use of the Hicksian demands enables to write the cost function associated to (2a) that are at the core of any welfare or situation comparison as:

(5) $$C(p_1, p_2, \mathbf{q}, \overline{U}) \equiv p_1h_1(p_1, p_2, \mathbf{q}, \overline{U}) + p_2h_2(p_1, p_2, \mathbf{q}, \overline{U})$$

while use the Marshallian demands enables to write the partial indirect utility function associated to (2b) as:

(6) $$V(p_1, p_2, \mathbf{q}, y) \equiv U(m_1(p_1, p_2, \mathbf{q}, y), m_2(p_1, p_2, \mathbf{q}, y), m_z(p_1, p_2, \mathbf{q}, y))$$

As noted by Hanemann and Morey (1992), the cost function defined is associated to a partial utility function and does not allow to compute standard compensating or equivalent variations in income. Nevertheless, this cost function provides a basis to define partial compensating variations in soft drink expenditure from state $\mathbf{q}_0$ to state $\mathbf{q}_1$ ($CV(.)$):

(6a) $$\overline{U}_0 \equiv V(p_1, p_2, \mathbf{q}_0, y) = V(p_1, p_2, \mathbf{q}_1, y - CV(p_1, p_2, \mathbf{q}_0, \mathbf{q}_1, \overline{U}_0))$$

or equivalent variations in soft drink expenditure from state $\mathbf{q}_0$ to state $\mathbf{q}_1$ ($EV(.)$):

(6b) $$\overline{U}_1 \equiv V(p_1, p_2, \mathbf{q}_0, y + EV(p_1, p_2, \mathbf{q}_0, \mathbf{q}_1, \overline{U}_1)) = V(p_1, p_2, \mathbf{q}_1, y).$$

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[13] The uniqueness is not necessary but is assumed for simplicity.

Definition of the relationships between* q, x_1, x_2 *and z

When comparing the characteristics of tap water, bottled water and the other soft drinks it seems natural, almost tautological, to say that: i-these three goods share the characteristics of non-alcoholic beverages (justifying, at least to some extend, our separability assumptions) and ii-tap water and bottled water share the characteristics of being water. The last remark imply that a rational consumer considers that bottled water is a closer substitute of tap water than the other soft drinks are. Formally, such an assertion can be written in terms of marginal rates of substitution as:

(7) Whenever: $U_z \geq 0$, we have: $\left.\dfrac{d^2x_2}{-dx_1dz}\right|_{u=cst} < 0$.

That is, along an indifference utility curve, the marginal rate of substitution of bottled water for the other soft drinks decreases as the (desired) consumption of tap water increases. This assumption can be interpreted by reference to the central hypothesis in economics, that of diminishing marginal rate of substitution. By the strict quasi-concavity assumption in (3a), we have:

$$\left.\frac{d^2x_2}{-dx_1dx_1}\right|_{u=cst} < 0$$

In standard textbooks, this inequality is said to reflect the facts that: i-a given good is its closest substitute and ii-consumers have a basic inclination to diversification (i.e., have convex preferences). Using this, assumption (7) can be interpreted as follows: a consumer having a basic inclination to diversification would need smaller amounts of (other) soft drinks to compensate for a decrease in bottled water consumption as tap water (when it is desired) consumption increases because bottled water is a closer substitute of tap water than it is of the other soft drinks. We can derive the implications in terms of Hicksian demand pattern by solving the following constrained cost minimization program:

(8) $$\underset{x_1,x_2}{Max} - (p_1x_1 + p_2x_2) + \gamma\left(U(x_1,x_2,z,\mathbf{q}) - \overline{U}\right)$$

Using standard comparative statics (for interior solutions) and noting γ* the optimal value of the Lagrange multiplier γ and $h_i^c(.)$ the constrained Hicksian demands, one obtains:

(9) Whenever: $U_z(h_1^c,h_2^c,z) \geq 0$, we have: $$\frac{dh_1^c}{dz} = \frac{1}{\Delta^c}\left(\frac{p_2}{\gamma^*}\right)^3 \left.\frac{d^2x_2}{-dx_1dz}\right|_{u=cst} < 0$$

where all functions are taken at (h_1^c,h_2^c,z), Δ^c is the (positive) determinant of the bordered Hessian of $U(.)$ in (x_1 , x_2) and U_i (.) is the partial derivative of $U(.)$ in x_i. That is, in Neill's (1988) terminology, where tap water is desired by the consumer, tap water and bottled water are Hicksian substitutes. Note that, given (3a), (7) is a necessary and sufficient condition for (9).

We now need to establish the relationships that are supposed to link **q** and the demands of the market goods. Quality is defined as a characteristic of good that increases desirability of this good for the consumer. Hence if quality is considered as a good, it can be defined as the "best" complement of the good to which it is associated. Formally, this can be written in terms of marginal rates of substitution as:

(10) Whenever: $U_z(h_1^c,h_2^c,z) \geq 0$ and $z \neq 0$, we have: $$\left.\frac{d^2x_i}{-dzdq_k}\right|_{u=cst} > 0,\ k = a,b\ ;\ i = 1,2.$$

That is, an increase in tap water quality makes a decrease in (desired) tap water consumption more harmful for the consumer. This simply comes from the fact that an increase in **q** leads to an increase in the desirability of z. Equation (10) defines the relationship between **q** and z. Equation (9) defines the relationship between z and x_1. It still remains to define how the relationship between z and x_1 is affected by **q**. In order to do this, we roughly need i-to rank the desirability of tap water of various quality with respect to desirability of bottled water and ii-to rank the presumed quality of bottled water within the set of potential qualities of tap water. We begin here with the second question. Provided that bottled water is unambiguously safe because of compulsory controls, is supposed to have diet and medical properties and is chosen by the consumer according to his taste, one can say that whatever is the value of **q**, consumption of a given quantity of bottled water provides higher utility to the consumer than consumption same quantity of tap water does. Formally, this can be written as:

(11) $\forall \mathbf{q},\ U(x_1, x_2, z, \mathbf{q}) < U(x_1 + z, x_2, 0, \mathbf{q})$

Provided that bottled water has to be purchased, is voluminous and is heavy to carry, this assumption seems rather strong. However, almost every household now has got a car and goes regularly to supermarkets to buy food. Under these circumstances, the marginal transport cost associated to the bottled water purchase can be considered as limited. Note that writing equation (11), we consider that tap water is not an essential good in soft drink utility. This assumption is natural since bottled water is a good that has all the advantages of tap water and (almost) none of its inconvenient. Now, what are the effects of **q** on the relative desirability of tap water and bottled water? Equation (11) states that bottled water is drinking water of the highest quality. Thus, intuition suggests that the higher the quality of tap water is the closer to those of bottled water are the characteristics of tap water. In other words, tap water becomes a closer substitute of bottled water as **q** increases. Formally, this can be written in terms of marginal rates of substitution as:

(12a) Whenever: $U_z(h_1^c, h_2^c, z) \geq 0$ and $z \neq 0$, we have: $\left.\dfrac{d^2 x_2}{-dx_1 dq_k}\right|_{u=cst} < 0,\ k = a, b.$

It can be noted that (3c) implies that:

(12b) Whenever: $U_z(h_1^c, h_2^c, z) \geq 0$ and $z = 0$, we have: $\left.\dfrac{d^2 x_2}{-dx_1 dq_k}\right|_{u=cst} = 0,\ k = a, b,$

i.e., that tap water quality only affects utility if tap water is consumed. Indeed, the interpretation of (12a) is very close to that of (7). Equation (12a) indicates that the desirability of bottled water is lowered by an increase in **q**. As **q** increases, tap water becomes a closer substitute of bottled water. Thus, when tap water is consumed, an increase in its quality leads to a decrease in the desirability of bottled water if the considered consumer exhibits an inclination to diversification.

Now, having formalized our prior assumptions on the characteristics of the different soft drinks in terms of relative desirability (i.e. only ordinal concepts), it is possible to derive some of the patterns of the soft drinks Hicksian demands. Using standard comparative statics (for interior solutions) and noting μ^* the optimal value of the Lagrange multiplier of the program (4a), one obtains after some tedious but straightforward computations:

$$\text{(13a)} \quad \frac{dh_1}{dp_1} = \left(-\frac{1}{\Delta}\right)\left(\frac{p_2}{\mu^*}\right)^3 \frac{U_{zz}}{p_2} < 0,$$

$$\text{(13b)} \quad \frac{dh_z}{dp_1} = \frac{1}{\Delta}\frac{p_2}{(\mu^*)^2}\left.\frac{d^2x_2}{-dx_1dz}\right|_{u=cst} > 0,$$

$$\text{(13c)} \quad \frac{dh_1}{dq} = \left(-\frac{1}{\Delta}\right)\left(\frac{p_2}{\mu^*}\right)^3\left[\frac{p_2}{\mu^*}\left.\frac{d^2x_2}{-dx_1dz}\right|_{u=cst}\left.\frac{d^2x_2}{-dzdq}\right|_{u=cst} - U_{zz}\left.\frac{d^2x_2}{-dx_1dq}\right|_{u=cst}\right] < 0$$

and:

$$\text{(13d)} \quad \frac{dh_z}{dq} = \left(-\frac{1}{\Delta}\right)\left(\frac{p_2}{\mu^*}\right)^4\left[\left.\frac{d^2x_2}{-dx_1dz}\right|_{u=cst}\left.\frac{d^2x_2}{-dx_1dq}\right|_{u=cst} - \left.\frac{d^2x_2}{-dzdq}\right|_{u=cst}\left.\frac{d^2x_2}{-dx_1^{\,2}}\right|_{u=cst}\right] > 0.$$

Equation (13c) indicates that bottled and supplied water quality are Hicksian substitutes while equation (13d) indicates that tap water and supplied water quality are Hicksian complements in the soft drink partial utility. Equation (13b) indicates that tap water and bottled water are Hicksian substitutes. These patterns suggest use of concepts similar to Mäler's (1974) weak complementarity and Feenberg and Mills' (1980) weak substitutability in order to define conditions for the expenditure function recovery in terms of price regime situations.

Conditions for recovery the expenditure functions

According to Mäler's definition, tap water and the quality of supplied water are weakly complementary if:

a-they are Hicksian complements $\frac{dh_z}{dq_k} > 0$, $k = a, b$,

b-there exists a price system (p_1^c, p_2^c) such that whenever $p_1 \leq p_1^c$ and $p_2 \leq p_2^c$ we have: $h_z(p_1, p_2, q, \overline{U}) = 0$, i.e. the Hicksian demand of tap water is choked off

and:

c- whenever $p_1 \leq p_1^c$ and $p_2 \leq p_2^c$ we have: $\frac{\partial C(p_1, p_2, \mathbf{q}, \overline{U})}{\partial q_k} = 0$, $k = a, b$.

According to Feenberg and Mills' definition, bottled water and the quality of supplied water are weak substitutes if:

d- they are Hicksian substitutes $\frac{dh_1}{dq_k} < 0$, $k = a, b$

and:

e-there exists a price system (p_1^{cc}, p_2^{cc}) such that whenever $p_1 \leq p_1^{cc}$ and $p_2 \leq p_2^{cc}$ we have: $\frac{\partial C(p_1, p_2, \mathbf{q}, \overline{U})}{\partial q_k} = 0$, $k = a, b$.

By application of the Envelope Theorem to the cost minimization program (4a) and using assumption (3c), one easily obtains that:

$$(14) \qquad \frac{\partial C(p_1, p_2, \mathbf{q}, \overline{U})}{\partial q_k} = 0 \quad \Leftrightarrow \quad h_z(p_1, p_2, \mathbf{q}, \overline{U}) = 0$$

Using the result (13d) that tap water quality strictly increases tap water consumption, in order to check that conditions *a-e* are met in our case, one just needs to check that there exists a price system that chokes off the demand for tap water where $\mathbf{q} = \mathbf{q}_{max}$. As a result, the price systems (p_1^{cc}, p_2^{cc}) and (p_1^c, p_2^c) are analogously defined. Assumption (11):

$$\overline{U} = U(h_1, h_2, h_z, \mathbf{q}) < U(h_1 + h_z, h_2, 0, \mathbf{q})$$

indicates that it is always possible to get at least the utility level $\overline{U}$ by totally substituting consumption of bottled water for consumption of tap water. Equation (13b) indicates that lowering the price of bottled water leads to a decrease in the demand of tap water and to an increase in the demand of bottled water. Thus, simply lowering the bottled water price may be a solution to get a "choke" price system. However, the previous assumptions do not ensure the existence of a "choke" price system.

We simply assume that this "choke" price system generally exists. Moreover, in order to avoid some difficulties (Smith, 1991), we assume that it is strictly positive. To be fully developed, arguments in favor of this assumption could rely on satiation effects. Such a development is out of the scope of this paper. Moreover, it would considerably complicate the entire analysis. We just provide some intuition about it and present the main assumptions upon which it relies. Intuition suggests that consumption of beverages can reach satiation, at least for physiological reasons. The satiation level for water may depend on the household composition, on the age of its members, etc. It may also depend on the level of consumption of the other beverages. But it does not depend on tap water quality, it is only defined over total consumed water quantity. As the price of bottled water continuously decreases, consumption of bottled water increases to finally reach the satiation level of water consumption. Given that bottled water is not only drunk for thirst-quenching, but also for diet or medical purpose, consumers' marginal willingness to pay for bottled water can be considered as always non-negative, even at the satiation level. However, where bottled water is consumed up to the water satiation level, consumers' marginal willingness to pay for tap water is likely to be negative since i-at the water satiation level the consumer's marginal utility of thirst-quenching is zero while ii-the marginal utility of the adverse effects of tap water can be considered as always negative. Under these assumptions, the price that sets bottled water consumption at the consumer's satiation level of water is i-strictly positive and ii-implies a corner solution in tap water consumption. Under these assumptions, lowering the price of bottled water up to the point where bottled water consumption reaches the consumer's satiation level allows to define a strictly positive "choke" price system. Furthermore, according to this analysis, one can say that the price of bottled water that chokes off tap water consumption increases as: i- $\overline{U}$ and p_2 increase and as: ii- $\mathbf{q}$ decreases.

Assuming that a strictly positive choke price system exists enables to solve the problem of the identification of the expenditure function. However, to be useful in applied work, this choke price system must be determined. Consider an initial situation defined by $(p_1, p_2, \mathbf{q}, \overline{U})$. According to our previous analysis, a "choke" price system (p_1^c, p_2) can be defined by the condition:

(15) $\forall p_1 \leq p_1^c,\quad h_z(p_1, p_2, \mathbf{q}_{\mathbf{max}}, \overline{U}) = 0$

Condition (15) simply states that for any bottled water price inferior to p_1^c, the Hicksian demand for tap water is choked off. Being defined on the Hicksian demand of an unobservable good, condition (15) can't be used as such to empirically determine p_1^c. However, equation (9):

$$\text{Whenever: } U_z(h_1^c, h_2^c, z) \geq 0, \text{ we have: } \frac{dh_1^c}{dz} = \frac{1}{\Delta^c}\left(\frac{p_2}{\gamma^*}\right)^3 \left.\frac{d^2x_2}{-dx_1dz}\right|_{u=cst} < 0$$

indicates that increasing consumption of tap water decreases bottled water consumption. Thus, condition (15) can be restated in terms of Hicksian demands as:

(16) $\forall p_1 \leq p_1^c,\quad \dfrac{dh_1(p_1, p_2, \overline{U}, \mathbf{q})}{dq_k} = 0,\quad k = a, b.$

To be useful in applied work, condition (16) must now be restated in terms of Marshallian demands. Using duality relations, one obtains:

$$\frac{dh_1(p_1,p_2,\mathbf{q},\overline{U})}{dq_k} = \frac{dm_1(p_1,p_2,\mathbf{q},C(p_1,p_2,\mathbf{q},\overline{U}))}{dq_k} + \frac{dm_1(p_1,p_2,\mathbf{q},C(p_1,p_2,\mathbf{q},\overline{U}))}{dy}\frac{dC(p_1,p_2,\mathbf{q},\overline{U})}{dq_k} \qquad k=a,b \tag{17}$$

This, allows us to restate condition (15) as:

$$\forall p_1 \leq p_1^c,\ \frac{dm_1(p_1,p_2,y,\mathbf{q})}{dq_k}=0 \text{ and } \frac{dm_2(p_1,p_2,y,\mathbf{q})}{dq_k}=0 \quad k=a,b \tag{18}$$

Condition (18) can be used in applied work since it simply indicates that consumers supplied with various supplied water quality but having the same amount of soft drink expenditures and the same preferences will purchase equal amounts of bottled water and of other soft drinks only if the price system they face chokes off their tap water consumption. As such, condition (18) can used in applied work. It only defines conditions on Marshallian demand patterns. It defines conditions easily checked where standard demand systems are estimated.

2. The empirical model and the empirical recovery of the cost function parameters

Due to lack of data related to tap water quality and consumption, we are not able to estimate a structural model of demand of soft drinks. As a result, we can't impose the weak complementarity and substitutability properties presented in the previous section as it is warranted by Larson (1991) and Smith (1991). This motivates our use of an empirical approach inspired by the studies related to equivalence scales estimation (See e.g., Blundell and Lewbel, 1991).

We first show that estimation of compensating variations in income is analogous to estimation of equivalence scales. Both rely on similar logic. Both involve expenditure functions, reference utility levels and reference state levels and, more importantly, aim at comparing situations or welfare by use of monetary measures. We then describe how the empirical procedures usually used for equivalence scales estimation can be adapted for the estimation of public good values. More specifically, we show how the standard theoretical concepts developed for public valuation can be used within the empirical framework developed for equivalence scale measurement.

Partial compensating variations in income and true cost of drinking indices

Here, we restrict the analysis to the estimation and the interpretation of equivalence scales or equivalently to the estimation of true cost of soft drink (sub)indices. According to (Deaton and Muellbauer, 1980a), the quantity:

$$(19) \quad \frac{C(p_1, p_2, \mathbf{q}_1, \overline{U}_0)}{C(p_1, p_2, \mathbf{q}_0, \overline{U}_0)} \quad \text{where } \overline{U}_0 \equiv U(m_1, m_2, m_z, \mathbf{q_0}) = V(p_1, p_2, \mathbf{q_0}, y)$$

has the form of a true cost of living (sub)index. It can be interpreted as price index of soft drink utility level $\overline{U}_0$ where $\mathbf{q}_0$ is taken as the reference state. For short and by reference to the so-called true cost of living index, we label this ratio as the "true cost of drinking index"

(TCDI) in state $\mathbf{q}_1$, $\mathbf{q}_0$ being the invariant reference state. In order to provide an interpretation for this price subindex, we first derive the effects of changes of $\mathbf{q}$ on *V(.)* and *C(.)*. Using the Envelope Theorem, one obtains that:

$$\text{(20a)} \quad \frac{\partial C(p_1, p_2, \mathbf{q}, \overline{U})}{\partial q_k} = \mu \frac{\partial U(h_1, h_2, h_z, \mathbf{q})}{\partial q_k} = \mu U_k(h_1, h_2, h_z, \mathbf{q}) \geq 0 \qquad k = a, b$$

and:

$$\text{(20b)} \quad \frac{\partial V(p_1, p_2, \mathbf{q}, y)}{\partial q_k} = \frac{\partial U(m_1, m_2, m_z, \mathbf{q})}{\partial q_k} = U_k(m_1, m_2, m_z, \mathbf{q}) \geq 0 \qquad k = a, b.$$

By (20a)[14], the cost of achieving the partial utility level $\overline{U}$ increases as the quality of tap water decreases. Also, it is easily shown that a deterioration (improvement) in $\mathbf{q}_1$ tends to increase (decrease) TCDI in state $\mathbf{q}_1$. It is more (less) costly for a consumer supplied with low (high) quality water to achieve a given partial utility $\overline{U}_0$ that it is for a consumer supplied with high (low) quality water. The TCDI in state $\mathbf{q}_0$ is equal to 1. As such, the TCDI is a good indicator of the effects of $\mathbf{q}$ on consumers' welfare with respect to soft drink consumption.

It is easily shown that the TCDIs have the same information content as the corresponding variations in soft drink expenditure. The former are expressed in terms of cost ratio whereas the later are expressed in terms of difference in expenditures.

However, the fact that these concepts are defined with respect to a partial utility function must be acknowledged and commented. In particular and as noted by Deaton and Muellbauer (1980a), the TCDI is only a true cost of living subindex. It is not a true cost of living index, i.e. the index used to define standard equivalence scales. Similarly, Hanemann

[14] Note that, by assumption (3c), these derivatives are null if and only if h_z, respectively, m_z is null. In fact, assumption (3c) implies that $\mathbf{q}$ has only use value associated with the consumption of tap water for the consumer.

and Morey (1992) note that partial compensating variations in income are likely to differ substantially from the standard compensating variations in income, the later being defined with respect to the global utility function. This negative result leads Hanemann and Morey (1992) to cast doubt on the usefulness of partial expenditure function estimations, at least with respect to policy design.

However, Hanemann and Morey (1992) also show that the partial compensating variation $CV(p_1, p_2, \mathbf{q}_0, \mathbf{q}_1, \overline{U}_0)$[15] is a lower bound on the desired or conventional compensating variation in income. Thus if $\mathbf{q}_0 > \mathbf{q}_1$, $CV(p_1, p_2, \mathbf{q}_0, \mathbf{q}_1, \overline{U}_0)$ is an upper bound of how much the consumer would have to be paid to accept the deterioration of the tap water quality from $\mathbf{q}_0$ to $\mathbf{q}_1$. A simple interpretation of Hanemann and Morey's (1992) result using the Le Châtelier Principle and the TCDIs tends to show that measurement of TCDI or partial compensating variation in income may nevertheless be quite useful. In fact they are useful because i-they are easily interpretable and ii-partial utility of soft drink seems to be an operational concept.

Consider a consumer initially in state $\mathbf{q}_0$ and finally in state $\mathbf{q}_1$ where $\mathbf{q}_0 > \mathbf{q}_1$. Deterioration from $\mathbf{q}_0$ to $\mathbf{q}_1$ tends to increase the TCDI faced by the considered consumer. Due to this implicit price increase, this consumer would have chosen a lower level of soft drink utility than $\overline{U}_0$ if he was free to do so. That is, in the first stage of the two stage budgeting procedure implied by our separability assumption, the consumer would have reduce his demand for soft drink utility, this partial utility being more expensive in the final state. As a result, by decreasing his level of soft drink utility, he would have partially overcome this soft drink price index increase. This adjustment lies at the root of Hanemann and Morey's (1992) result. It is not allowed where only partial compensating variations in income are

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[15] See equation (6a).

computed while it is allowed where standard compensating variations in income are computed. In the empirical part of this study, we estimate price indices of soft drink utility, i.e. TCDIs. The previous discussion show that they allow situation comparisons in partial utility of soft drinks and that they are easily interpretable. Moreover, in 1989 the French Government changed the fiscal status of the soft drinks. These are now considered as necessity goods and are subject to a 5,5% value added tax whereas they were considered as luxury goods before 1989 and were subject to a 18,6% value added tax. This status change reflects the fact the utility of soft drinks is considered as a priority by the French Government and provides another argument in favor of the interpretation of the TCDIs as useful (partial) relative welfare measures.

The empirical specification

To fix ideas, we assume that consumers' have preferences for which the cost function has the so-called PIGLOG form:

(21) $lnC(p_1, p_2, U; q) = A(p_1, p_2; \mathbf{q}) + U B(p_1, p_2; \mathbf{q}), \qquad U \in [0,1]$

This form can be interpreted as a first order approximation in U of any cost function logarithm. According to Muellbauer's (1976) interpretation the functions $A(.)$ and $B(.)$ can be regarded as costs of subsistence and bliss, respectively, at the normalization point. As functions of **q**, those costs depend on tap water quality[16]. Thus, the forms of these functions implicitly embody the Hicksian demand function for tap water. Given that we have no strong prior about the true forms of $A(.)$ and $B(.)$, we adopt Deaton and Muellbauer's (1908b) choice of "almost ideal" flexible functional forms. That is, we assume that:

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[16] Since, we do not use the different dimensions of **q**. in what follows, we simply consider the quality measure as a scalar: q.

(22a) $$A(p_1,p_2;q) \equiv \alpha_0(q)+\sum_k \alpha_k(q)lnp_k + \frac{1}{2}\sum_k\sum_l \gamma_{kl}(q)lnp_k lnp_l$$
$$\equiv \alpha_0(q)+a(p_1,p_2;q)$$

and:

(22b) $$B(p_1,p_2;q) \equiv \beta_0(q)\prod_k p_k^{\beta_k(q)} \equiv \beta_0(q)b(p_1,p_2;q).$$

The prefix *ln* indicates a transformation by natural logarithm. For (21) to have the properties of cost function (excepted concavity in prices), the following parametric restrictions must be imposed:

(23) $\sum_k \alpha_k(q)=1$, $\sum_k \gamma_{kl}(q)=0, \gamma_{kl}(q)=\gamma_{lk}(q)$ and, $\sum_k \beta_k(q)=0$

Noting r the price ratio p_1 / p_2, we can rewrite (21), (22a) and (22b) as:

(24) $$lnC(r,p_2,U;q) \equiv \alpha_0(q)+\alpha_1(q)lnr+lnp_2+\frac{1}{2}\gamma_{11}(q)(lnr)^2+U\beta_0(q)r^{\beta_1(q)}.$$

(25a) $$A(r,p_2;q)=\alpha_0(q)+\alpha_1(q)lnr+lnp_2+\frac{1}{2}\gamma_{11}(q)(lnr)^2$$

and:

(25b) $$B(r,p_2;q)=\beta_0(q)r^{\beta_1(q)},$$

respectively. Application of Shephard's lemma and use of the equality of the Marshallian and Hicksian demands at the optimal consumption level allows derivation of the Marshallian demand functions associated to (24). Because only two goods are considered, we only present the demand function of bottled water, the demand for the other soft drinks being easily recovered by use of the adding-up condition. Expressed in terms of budget share, the Marshallian demand of bottled water derived from (24) has the following form:

$$w_1(r,p_2,y;q) \equiv \frac{p_1 m_1(r,p_2,y;q)}{y}$$

(26) $$\equiv \alpha_1(q) - \beta_1(q)\alpha_0(q) + \gamma_{11}(q) ln r + \beta_1(q)\left[ln\left(\frac{y}{p_2}\right) - \alpha_1(q) ln r - \frac{1}{2}\gamma_{11}(q)(ln r)^2 \right]$$

The cost function parameter identification problem stems from the fact that the term $\beta_0(q)$ does not appear in equation (26). This cost function parameter can not be estimated from observed ordinary demands.

A simple procedure to recover the cost function parameters

Expressed in logarithm, the TCDI for situation characterized by tap water quality q_1 and q_0 and taking $U_0 = V(r, p_2, y; q_0)$ as the reference utility level can be written as:

(27a) $$ln\left[\frac{C(r,p_2,U_0;q_1)}{C(r,p_2,U_0;q_0)}\right] \equiv [\alpha_0(q_1) + a(r,p_2;q_1)] - [\alpha_0(q_0) + a(r,p_2;q_0)] + U_0[\beta_0(q_1)b(r,p_2;q_1) - \beta_0(q_0)b(r,p_2;q_0)]$$

where:

(27b) $$U_0 = \frac{lny - \alpha_0(q_0) - a(r,p_2;q_0)}{\beta_0(q_0)b(r,p_2;q_0)} \equiv 1.$$

Note that without loss of generality, one can choose any value to scale U_0, the utility being defined up to a strictly increasing transformation. This simply provides a scale for the $\beta_0(q)$. parameters. Note that imposing $U_0 = 1$ allows to "identify" $\beta_0(q_0)$ but not $\beta_0(q_1)$.

Blundell and Lewbel (1991) note that without further restriction or extra information, observation of ordinary demand provide no information about equivalence scales in a single price regime. In studies dealing with equivalence scales, this problem is often[17] solved by the assumption that $B(q)$ does not depend on q, i.e., the so-called "independence of the base

[17] See also Lechene (1993) for a comprehensive survey related to this topic.

utility level assumption". This assumption is quite strong in our case, since it implies that the ratio of the cost functions does not depend on the utility level to be reached. We could also impose a less restrictive assumption: $\beta_0(q)$ does not depend on q. In this case a simple redefinition of the utility scale would solve the problem. It is still a strong assumption since it implies that the way the utility level affects the expenditure function depends only on q trough its effects on the price ratio r. This would imply tap water quality has no direct effect on the bliss cost level. Roughly, this would imply that changes in q only affect consumers' welfare through the reallocation of marketed soft drink demands they imply.

However, Blundell and Lewbel (1991) also show that if the true value of equivalence scales (that is for a given U_0) is known in one positive price regime, then Marshallian demands can be used to recover the true values of all equivalence scales in all other price regimes. This shows that the existence of the "choke" price regime is a crucial point in our case. Further, it shows that a common practice for environmental good valuation, i.e. the definition of a price regime implying "cost independence" situation, may also solve, at least partially, the problem of equivalence scale identification. This provides a bridge to use approaches developed for estimation of equivalence scales for estimation of public good values.

In order to show this, assume that that the "choke" price ratio r^c is known. One simply recovers $\beta_0(q_1)$, the last parameter to be computed in (27), by using condition (14) along with (27), i.e. using equations:

(28a) $$ln\left[\frac{C(r^c,p_2,1;q_1)}{C(r^c,p_2,1;q_0)}\right]=\left[\alpha_0(q_1)+a(r^c,p_2;q_1)\right]-\left[\alpha_0(q_0)+a(r^c,p_2;q_0)\right]$$
$$+\left[\beta_0(q_1)b(r^c,p_2;q_1)-\beta_0(q_0)b(r^c,p_2;q_0)\right]=0$$

where:

(28b) $$\frac{lny-\alpha_0(q_0)-a(r^c,p_2;q_0)}{\beta_0(q_0)b(r^c,p_2;q_0)}=1.$$

Equation (28a) simply states that where tap water demand is choked off in both states (i.e. in states q_1 and q_0) thank to a low price of bottled water, the TCDI in state q_1 is equal to one. This result can be roughly restated as: where tap water is not consumed, tap water quality does not matter. Formally, this comes from equation (14).

It still remains to determine the "choke" price ratio r^c. Note that with our expenditure function choice, we only need to identify a single "choke" price regime for a single utility level (not the whole equivalence scale) since we only need to recover a single parameter. A "choke" price system can thus be defined as the price ratio r^c satisfying condition (18) for any given value of $(y\ ,\ p_2)$. This "choke" price ratio is simply recovered by solving the following equation:

$$w_1(r^c,p_2,y;q_0)=w_1(r^c,p_2,y;q_1)$$

$$\Leftrightarrow$$

$$\text{(29)}\quad \left(\left[\alpha_1(q_0)-\beta_1(q_0)\left(\alpha_0(q_0)-ln\left(\frac{y}{p_2}\right)\right)\right]-\left[\alpha_1(q_1)-\beta_1(q_1)\left(\alpha_0(q_1)-ln\left(\frac{y}{p_2}\right)\right)\right]\right)$$
$$+\left(\left[\gamma_{11}(q_0)ln\,r-\beta_1(q_0)\alpha_1(q_0)\right]-\left[\gamma_{11}(q_1)ln\,r-\beta_1(q_1)\alpha_1(q_1)\right]\right)ln\,r$$
$$-\left(\frac{1}{2}\beta_1(q_0)\gamma_{11}(q_0)-\frac{1}{2}\beta_1(q_1)\gamma_{11}(q_1)\right)(ln\,r)^2=0$$

Solving this second order equation in lnr^c, provides two values for r^c. If the problem is correctly specified one should find at least one solution such that $r > r^c$. [18] Several comments are in order with respect to this procedure of recovery of the choke price system. The first one is that if r^c is very different from r, it must be used with caution since it may be determined by using the estimated demand out of the domain where they can be considered as good approximations to the true ones[19-20]. The second one is that (29) may have no solution.

[18] Here r is the price ratio that, along with y and p_2, allows a consumer in state q_0 to achieve the reference utility level U_0 (see equation 27b).

[19] Hence, if both solutions to (28) are inferior to r, one should choose the closest to r.

However, if one observes that the share difference $w_1(r^c, p_2, y; q_0) - w_1(r^c, p_2, y; q_1)$ tends to be very close to zero as r^c decreases, one may nevertheless judge that the model is correctly specified. This leads us to our last comment. Determining r^c by directly solving (29) fails to recognize that estimated demand equations are only approximations of the true ones. According to this point, a reliable way to determine r^c should rely on some statistical procedure. We propose such a (simple) procedure in Appendix 1.

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[20] Note that the utility level achieved by consumers in states q_1 and q_0 with the choke price regime (r^c, p_2) and soft drink expenditure y is higher that U_0. With $r^c < r$, we have:

$$V(r, p_2, y, q_0) < V(r^c, p_2, y, q_0) = V(r^c, p_2, y, q_1),$$

indirect utility functions being decreasing in prices.

3. Implementation of the approach in the French case

The data

We use data provided by INSEE (*Institut National de la Statistique et des Etudes Economiques*): the Food Consumption Surveys (*Enquêtes Consommation Alimentaire*). We have currently access to 7 surveys, one every second year from 1979 to 1991. Each survey provides a random sample of the population each year where it is performed. About 9000 households are surveyed each time, excepted in 1989 when only 3000 households were surveyed. Apart from standard demographic and economic characteristics (households' composition, localization, income, *etc*), it provides specific data on food consumption at a rather detailed level. However, the information content of these surveys is very difficult to exploit at the individual household level. Each household is surveyed during only one week, and is asked to report its food purchases in terms of quantity and expenditures. For goods such as bottled water that is generally packaged in France as sets of six bottle of 1 or 1,5 liter this survey method originates serious problems. At the individual household level, relevant econometric models of demand need to take into account infrequency of purchase, corner solutions and censoring[21] features. Even if considerable progress has been performed in this research area, estimation of such models still remains difficult in practice (Gouriéroux, 1989).

A way to avoid these problems is to work with data aggregated over households. We used the exact aggregation procedure presented by Blundell *et alii* (1993)[22] and that is allowed by the Deaton and Muellbauer's (1980b) demand system model. Thank to the large number of surveyed households, we defined 8 cohorts of six-year age bands and aggregated the households of these cohorts as "representative aggregated households" in each survey. For

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[21] Where the purchased quantity is null, prices are not reported.

[22] See also Cardoso and Gardes (1996).

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 28 years old in 1979, 30 years old in 1981, etc. Such a procedure is used for the construction of pseudo-panels (Deaton, 1985). However, we do not construct a pseudo-panel, i.e. a set of pseudo- or mean individuals for each defined cohort in each survey, we construct a set of representative households for each defined cohort. The main advantage of the aggregation procedure is that it overcomes the infrequency of purchase and censoring problems. The main advantages of the by cohort aggregation procedure are threefold. Firstly, it generates more "aggregated observations" than does a simple global aggregation procedure. Secondly, it allows aggregation of households that are approximately at the same point of their respective life-cycle. Ultimately, this allows comparisons of "similar" households across time. This is important where welfare comparisons are to be made (Pollack, 1991). Thirdly, it allows the specification of dynamic models, a feature not allowed by use of series of independent cross-sections (Deaton, 1985). We eliminate the aggregated "representative households" that represent less than 100 individuals.

Formally, starting with N_{ct} individual household demands of the form:

$$(30)\quad w_{1ci,t} = \alpha_1 - \beta_1\alpha_0 + \gamma_{11}\, ln\, r_{ci,t} + \beta_1\left[ln\left(\frac{y}{p_2}\right)_{ci,t} - \alpha_1\, ln\, r_{ci,t} - \frac{1}{2}\gamma_{11}(ln\, r)_{ci,t}^{\;2} \right] + e_{ci,t}$$

$$ci = 1,\ldots,N_{ct}$$

for cohort c in survey t, we ended with the demand of a single representative consumer of the form:

$$(31)\quad w_{1C,t} = \alpha_1 - \beta_1\alpha_0 + \gamma_{11}\, ln\, r_{C,t} + \beta_1\left[ln\left(\frac{y}{p_2}\right)_{C,t} - \alpha_1\, ln\, r_{C,t} - \frac{1}{2}\gamma_{11}(ln\, r)^2{}_{C,t} \right] + e_{C,t}$$

with:

$$(32) \qquad w_{1C,t} \equiv \frac{\sum_{ci=1}^{Nct} p_{1ci,t} x_{1ci,t}}{\sum_{ci=1}^{Nct} y_{ci,t}} \quad \text{and} \quad X_{C,t} \equiv \sum_{ci=1}^{Nct} \pi_{1ci,t} X_{ci,t}$$

where:

$$(33) \qquad \pi_{ci,t} \equiv \frac{y_{ci,t}}{\sum_{ci=1}^{Nct} y_{ci,t}} \quad \text{and } X = lnr,\ (lnr)^2 \text{ and } ln\left(\frac{y}{p_2}\right).$$

Thus, the bottled water budget share of the "representative consumer" ($w_{1C,t}$) is the share bottled water total expenditure of the cohort in the soft drink total expenditure of the cohort. Each explanatory variable of the "representative consumer" demand equation ($X_{C,t}$) is the sum of the explanatory variable ($X_{ci,t}$) of the total cohort weighted by the contribution of each household soft drink expenditure in the soft drink total expenditure of the cohort ($\pi_{ci,t}$).

The tap quality "indicators"

Given that we have no relevant measure of tap water quality over the studied period. We defined three areas in France by grouping the 95 *départements* (administrative areas similar in size to the U.S. counties) according to our prior on the quality of their supplied water and its evolution. Hence, we defined three sub-surveys, one for each area. The aggregation procedure was used for each sub-survey, giving us three sets of 60 "representative households". We used geological and topological arguments as well as observations of the bottled water consumption means per *département*. These three areas are represented in Figure 2. As such, our quality indicators are simply dummy variables.

We first defined what we called the Mountain Area (MA). Since supplied water in this area directly comes from preserved sources, tap water quality can be presumed as very good and constant over the 1979-1991 period. Households in this area represent about 25% of the surveyed population. Their bottled water consumption is very low at the beginning of the period (around 1 liter *per* household *per* week) and, despite a slight increase during the period, remains low in 1991 (around two liters *per* household *per* week) (See Figure 3a). This region is used as the reference area since one may reasonably assume that tap water quality is (and is perceived as) invariantly good in this area during the 1979-1991 period. An eventual structural change in soft drink demand in this area, i.e. a change not originated by price or income changes, may not be due to tap water quality. It may rather be originated by bottled water and/or soda advertising. Thus, if it exists, this structural change may certainly also have affected the demands of the other regions along the same ways.

We then defined what we call Industrial and Agricultural Plain Area (IAPA). This area is characterized by a high population density. It concentrates a large part of the French industries. It also includes the Large Paris Basin, the most fertile region of France where intensive agriculture is common practice since the early sixties. It is the area where the supplied water quality can be considered as the lowest, at least at the beginning of the period. It might have slightly decrease in consumers' minds. In this area, industrial and agricultural pollution problems are certainly combined with hard water problems, at least in the Large Paris Basin which is characterized by chalky grounds (Bureau *et alii*, 1997). Households in this area represent about 50% of the surveyed population. Their bottled water consumption is the highest at the beginning of the period (from around 2,5 liters *per* young household *per* week to around 3,5 liters *per* old household *per* week) and, due to a significant increase during the period remains one of the highest in 1991 (from around 3,5 liters *per* young household *per* week to around 5 liters *per* old household *per* week) (See Figure 3b).

Finally, we defined what we call the "Big West" Area (BWA). This area is characterized by a medium population density and a medium industrial activity. It is very heterogeneous from a geological point of view. Households in this area represent about 25% of the surveyed population. Their bottled water consumption lies in between that of the other areas at the beginning of the period (around 2 liters *per* household *per* week). Due to a dramatic increase during the period, it is one of the highest in 1991 (from around 3 liters *per* young household *per* week to around 4,5 liters *per* old household *per* week) (See Figure 3c). Anticipating the econometric analysis, it seems that a structural change has affected bottled water consumption in this region. If it is originated by tap water quality, tap water quality may be considered as medium-good at the beginning of the period, while it seems to be one of the lowest at the end of the period.

The econometric model and estimation procedure

All figures showing bottled water consumption indicate a positive correlation according to the age of the household (see Figure 3a-3c). Similarly, the figures representing the consumption of other soft drinks (juices, sodas, sparkling water)[23] tend to indicate a negative correlation according the age of the household (see Figure 4a-4c). After several specification researches, this effect is introduced in equation (31) by transformation of the parameter α_1 into a linear function of the (correctly aggregated according to equations (32) and (33)) natural logarithm of the age ($ln a_{C,t}$) of the household's head:

(34)
$$w_{1C,t} = (\alpha_{10} + \alpha_{11} \ln a_{C,t}) - \beta_1 \alpha_0 + \gamma_{11} \ln r_{C,t} + \beta_1 \left[\ln\left(\frac{y}{p_2}\right)_{C,t} - (\alpha_{10} \ln r_{C,t} + \alpha_{11} (\ln a \ln r_{C,t}) - \frac{1}{2}\gamma_{11} (\ln r)^2{}_{C,t} \right] + e_{C,t}$$

Structural changes, after several specification tries, are specified as dummy variables affecting the β_1 parameter. In the specification (34), this parameter becomes:

(35) $\beta_1 = \beta_{10} + \beta_{11} T(s)$ where $T(s) = 0$ if $t < s$ and $T(s) = 1$ otherwise .

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[23] The other soft drinks are aggregated by quantity. p_2 is thus an expense per quantity unit of soft drinks. Such an aggregation can be justified with cross-section data by the rigidity of the relative price structure of these goods (Deaton, 1988 and 1987). However, it ignors quality evolution over time.

In this case, a test of structural change is simply a standard test of the statistical significance of the β_{11} parameter estimate.

The demand equation of bottled water (34)-(35) is estimated for each sub-survey aggregated data set. We used two stage nonlinear least squares estimators in order to take into account the eventual endogeineity of the soft drink expenditure variable (y). Total income was used as instrumental variable in addition to price and age (and their combinations) variables that are exogenous. At least price variable are assumed as such[24]. The econometric model is thus just identified. The parameter s of (35) is estimated by grid search. Finally, the error terms $e_{C,t}$ are assumed to be independent and identically distributed.

[24] Assuming the exogeneity of price leads to neglect eventual quality effects (See Deaton, 1987 and 1988).

4. Results and first conclusions

The demand estimation

As no structural change was found for the MA and the IAPA, the bottled water demand was simply estimated without equation (35) for these regions. A significant structural change was found only for the BWA. Estimation results are presented in Table 1.

Table 1. Estimates (and parameter estimator standard deviation estimates) of the parameters of the bottled water demand for the three defined areas

Parameters	Mountain Area	Industrial and Agricultural Plain Area	"Big West" Area
α_0	12.54 (7.71)	9.86 (3.71)	6.20 (0.05)
α_{10}	-2.40 (1.59)	-2.57 (0.92)	-0.82 (0.32)
α_{11}	0.19 (0.07)	0.48 (0.12)	0.33 (0.08)
γ_{11}	0.85 (0.48)	0.82 (0.59)	-0.05 (0.05)
β_{10} *or* β_1	-0.32 (0.11)	-0.39 (0.10)	-0.53 (0.13)
β_{11}	-		0.46 (0.18)
s	-		1987

Two main points are in order. Firstly, only two of the MA demand are statistically significant at the 1% level while the others are only significant at a level close to 10%. Second, even apart from the structural change, the parameter estimates of the BWA demand equation seem very different from that of the other areas. In fact, as estimated, the structural change affects the demand since 1987. But Figure 1 and Figure 5 show that the real price of soft drinks decreased by 10% in 1989 when compared to 1988. This corresponds to the decrease from 18% to 5,5% of the value added tax of these goods in 1989. Since 1989, soft drinks are considered as necessary goods by the French State whereas they were considered as luxury goods. Hence, the structural change specification (35) may partially embody the price effects in the BWA equation. This is reflected in the pattern of its demand elasticities. This leads us to cast doubt on the validity of the parameter estimates of the BWA demand model.

In the MA and the IAPA, the estimated own price elasticities of the Hicksian[25] demand of bottled water are of about -.3 at the beginning of the period and of about -.7 in 1991. They slightly depend on households' age. In these areas, the estimated elasticity of the bottled water demand with respect to total soft drink expenditure is about equal to .30 in 1979 and decreases to be about equal to 0 in 1991. This evolution may be explained by the dramatic decrease in alcoholic beverages (mainly beers and low quality wines) observed in France during the period. These beverages seem to be close substitutes of the other soft drinks at the beginning of the period. Campaigns against alcohol abuse may have led to the exclusion of beers and wines out of the thirst-quenching beverage traditional group by the French consumers. Becoming the only "safe" goods remaining for thirst-quenching, soft drinks may have become more necessary for the French consumers. This also provides a justification in favor of the value added tax cut decided by the French Government in 1989. In the BWA, the estimated own price elasticities of the Hicksian demand of bottled water is steady and about equal to -.65 during the period. However, when compared with those of the other areas, the pattern of estimated elasticity of the bottled water demand with respect to total soft drink expenditure is surprising in the BWA. It is about equal to 0 at the beginning of the period and rises to end at .85 in 1991.

[25] Compensated on the soft drink utility.

Globally, these results seem intuitive for the MA and the IAPA. However, the results for the BWA clearly show that our specifications of the structural change must be improved or, at least, carefully checked.

The fact that no structural change was found in the MA indicate that no global factor has affected the pattern of the demand for bottled water within the soft drink group. Global factors such as real price effects or the decrease in alcoholic demand due to efficient campaign intended to alcohol abuse, have similarly affected the demand for all soft drinks. However, it can be noted that this changes may affect differently the young and the old households. Similarly the fact that no structural change was found in the IAPA also suggest that the perception of the tap water quality has not changed in this area. Thus, a non negligible part of the increase in the demand of bottled water in this area can be attributed to price effects. Nevertheless, the fact that these global changes have led to a more important increase in the demand of bottled water in the IAPA than in the MA suggests that tap water quality affects the effects of such changes. The situation seems strikingly different in the BWA since it seems that a structural change has affected the bottled water demand in this region. If it is originated by tap water quality, tap water quality may be considered as medium-good at the beginning of the period, while it seems to be one of the lowest at the end of the period. Such a decrease in tap water quality seems plausible since it could be explained by evolution of agricultural practices in this area. Prior to the Common Agricultural Policy (CAP) implementation in the early sixties, agriculture was mostly extensive and based on the crop-breeding association. Thank to global or specific CAP measures, agriculture has become intensive in this area. In the early nineties, Bretagne (in the north of the BWA) is the main area for pork and milk production in France. Poitou-Charentes (in the middle of the BWA) and Aquitaine (in the south of BWA) are major areas for oilseed production, respectively, (irrigated) corn production. In this area, especially in Bretagne, nitrates are now considered as a major problem with respect to the safety of the local water resources since the late eighties.

The estimated "true cost of drinking index"

In order to compare welfare across region, we take as reference the situation in the MA. The "choke" price ratios are computed according to the simplest method, i.e. by directly solving the equality of the Marshallian demand of bottled water in the MA with that of the same household (with the MA prices and expenditures) in the other areas. For most[26] of our 120 computations, the estimated "choke" price ratio show that if the bottled water price is cut in a range of 60%-75% of its initial level (that is almost the same across areas), households facing the same price for the other soft drinks and having a level of expenditure equal to the current expenditure level of the same household in the MA have equivalent Marshallian demands of market soft drinks. Thus, our estimations suggest that a decrease of about 70% in the bottled water price would chokes off the demand for drinking tap water in France. Figure 6a (Figure 6b) shows the pattern of the considered Marshallian demands as the bottled water price decrease for the IAPA (and the MA). The considered household's head is 40 years old in 1991 and the household is composed of two adults and a child. At the "choke" price it would consume 13 liters of bottled water. The patterns of the Marshallian demands suggests that by using the "statistical" procedure defined in Appendix 1 we may find a slightly higher "choke" price but a significantly lower bottled water consumption at the "choke" price regime.

In this application, we just computed the cost ratio:

$$\frac{C(r, p_2, U_{MA}; q_{BWA\,or\,IAPA})}{C(r, p_2, U_{MA}; q_{MA})} = \frac{C(r, p_2, U_{MA}; q_{BWA\,or\,IAPA})}{y_{MA}} \tag{36}$$

---

[26] We have some trouble with the youngest and the oldest households in both the BWA and the IAPA regions. This may be explained by our too rough specification of the age effects.

for each of the representative household of the MA to compare the situation of households in the BWA and in the IAPA with that of representative household in the MA. Prices do not vary much across regions. This ratio thus suffice to compare situations across regions. By computing expression (36), we compute the ratio of the cost that an household in the BWA or IAPA to reach the soft drink utility level of the same household gets currently in the MA on the cost currently incurred in the MA. This ratio is the true price subindex of soft drink in BWA or IAPA with the soft drink utility level reach in the MA as reference. For short, we label this ratio, the true cost of drinking index (TCDI) in the BWA or the IAPA.

We first comment the results for the IAPA. Figure 7a shows the TCDI as a function of age for the four median cohorts. For households in the IAPA region it lies between 3 and 4 at the beginning of the period and between 2 and 2,5-3 at the end. It indicates that older households generally have higher TCDIs. An explanation could be that they have more health considerations when choosing soft drinks. Moreover, younger households (especially those with children) may have more basic inclination for soft drinks such as sodas and juices and may less rely on water to satisfy their soft drink utility than the older households do. Thus a low tap water quality may affect more importantly old households than young households. Secondly, Figure 7 also indicates that the TCDI tends to decrease at the end of the period. This may be originated by the price decrease in soft drink prices that allows household to purchase more soft drinks, and especially bottled water and, as a result, to less rely on tap water consumption. The actual ratio: current soft drink expenditures in the IAPA over current soft drink expenditures in the IAPA is about equal to 1.5 in 1991 for every representative households. This suggests that the households, and particularly the oldest ones, in the MA have higher soft drink utility that the households in the IAPA. As explained in the previous section, households in the IAPA face a relatively high true soft drink price index and, as a result, allocate their income in favor of other consumptions than those of soft drinks. For them, soft drink utility is a relatively expensive "good". Thank to this flexibility in the income allocation process, the willingness to pay of households in the IAPA for tap quality equivalent to that of the MA would be lower than:

$$C(r, p_2, U_{MA}; q_{IAPA}) - C(r, p_2, U_{MA}; q_{MA})$$

as suggested by Hanemann and Morey's (1992) result.

Figure 7b, shows the TCDI in BWA as a function of age for the four median cohorts. The TCDI in the BWA is slightly lower than in the IAPA at the beginning of the period. However, it tends to dramatically increase at the end of the period whereas the TCDI in the IAPA tends to decrease, to finally decrease in 1991. Thus it seems that the structural change in tap water consumption in the BWA has, at least to a large extend, overcome the price decrease effect. However, the results for the BWA must be used with caution due to the structural identification problem described above.

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Appendix 1: A simple "statistical" method to recover the choke price

A crucial step of our approach is the estimation of a "choke" price ratio r^c that allows the recovery of the β_0 terms of the "Almost Ideal" expenditure functions. As explained above, for y, p_2, q and q', determining the "choke" price system defined as the price ratio r^c by using condition (20) is equivalent to solve the following equation:

$$w_1(r^c,p_2,y;q_0) = w_1(r^c,p_2,y;q_1)$$
$$\Leftrightarrow$$
$$\left(\left[\alpha_1(q_0)-\beta_1(q_0)\left(\alpha_0(q_0)-ln\left(\frac{y}{p_2}\right)\right)\right]-\left[\alpha_1(q_1)-\beta_1(q_1)\left(\alpha_0(q_1)-ln\left(\frac{y}{p_2}\right)\right)\right]\right)$$
$$+\left(\left[\gamma_{11}(q_0)lnr-\beta_1(q_0)\alpha_1(q_0)\right]-\left[\gamma_{11}(q_1)lnr-\beta_1(q_1)\alpha_1(q_1)\right]\right)lnr$$
$$-\left(\frac{1}{2}\beta_1(q_0)\gamma_{11}(q_0)-\frac{1}{2}\beta_1(q_1)\gamma_{11}(q_1)\right)(lnr)^2 = 0$$

This procedure of recovery of the choke price ratio simply consists in solving this second order equation in lnr^c. Driscoll (1994) shows that, for any strictly positive price system and soft drink expenditure, the AI expenditure function can be interpreted as a Taylor's approximation to the true one, i.e. that the AIDS can be interpreted as a Taylor's approximation to the true demand system. The main drawback of the previous approach, is that it fails to recognize that estimated demand equations are only approximations of the true ones. According to this point, a reliable approach to determine r^c should rely on some statistical procedure. We propose such a (simple) procedure in this appendix.

In what follows, θ_q denotes the parameter vector $\left[\alpha_0(q),\alpha_1(q),\beta_1(q),\gamma_{11}(q)\right]'$, **X** denotes the variable vector $\left[w_1,lnr,(lnr)^2,ln\left(\frac{y}{p_2}\right)\right]'$, **Z** denotes the instrumental variable vector $\left[1,lnr,(lnr)^2,lnI\right]'$, where lnI is the natural logarithm of the (correctly aggregated) households' income, and $\mathbf{C}_s$ denotes the variable vector $\left[lns,(lns)^2,lnd\right]'$, where s is a given value for the price ratio r and d is a given value for soft drink expenditure y deflated by p_2.

The two stages nonlinear least square estimator of θ_q based on the model:

$$w_{1C,t} = \alpha_1 - \beta_1\alpha_0 + \gamma_{11}\, ln r_{C,t} + \beta_1\left[ln\left(\frac{y}{p_2}\right)_{C,t} - \alpha_1\, ln r_{C,t} - \frac{1}{2}\gamma_{11}(ln r)^2{}_{C,t}\right] + e_{C,t}$$

where **Z** is used as the instrument vector can be defined as the optimal[1] Generalized Method of Moments estimator of θ_q based on the orthogonality conditions:

$$E\left[\mathbf{H}(\mathbf{Z},\mathbf{X};\theta_q)\right] \equiv E\left[\mathbf{Z}e(\mathbf{X};\theta_q)\right] = \mathbf{0}.$$

This estimator is denoted by $\hat{\theta}_{q,N}$, N being the total number of representative households in each area. Under the assumption that the observations are i.i.d. and other standard assumptions (see Hansen, 1982), this estimator is strongly consistent and its asymptotic distribution is given by:

$$\sqrt{N}(\hat{\theta}_{q,N} - \theta_q) \xrightarrow[N_q \to +\infty]{} \mathbf{N}\left(\mathbf{0}, \Sigma_q\right)$$

where:

$$\Sigma_q \equiv \left(\mathbf{J}_q{}'\Omega_q^{-1}\mathbf{J}_q\right)^{-1},$$

$$\mathbf{J}_q{}' \equiv E\left[\frac{\partial \mathbf{H}(\mathbf{Z},\mathbf{X};\theta_q)'}{\partial \theta'}\right] = -E\left[\mathbf{Z}\frac{\partial w_1(\mathbf{X};\theta_q)}{\partial \theta'}\right]$$

and:

$$\Omega_q \equiv E\left[\mathbf{H}(\mathbf{X},\mathbf{Z};\theta_q)\mathbf{H}(\mathbf{X},\mathbf{Z};\theta_q)'\right].$$

Using Slutsky's Theorem, one easily obtains that:

$$\sqrt{N}\left(w_1(\mathbf{C}_s;\hat{\theta}_{q,N}) - w_1(\mathbf{C}_s;\theta_q)\right) \xrightarrow[N \to +\infty]{} \mathbf{N}\left(0, \mathbf{W}_q{}'\Sigma_q\mathbf{W}_q\right)$$

where:

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[1] See Newey (1993) or Gouriéroux and Monfort (1989).

$$\mathbf{W}_q' \equiv E\left[\frac{\partial w_1(\mathbf{C}_s;\theta_q)}{\partial \theta'}\right].$$

Given the properties of $\hat{\theta}_{q,N}$, the matrices Σ_q, and $\mathbf{W}_q$ can be consistently estimated by their sample counterparts $\hat{\Sigma}_{q,N}$ and $\hat{\mathbf{W}}_{q,N}$. Finally, provided that the subsamples of representative households in different areas (e.g., for q and q' where $q \neq q'$) are independent, we have:

$$\sqrt{N}\begin{bmatrix} w_1(\mathbf{C}_s;\hat{\theta}_{q,N}) - w_1(\mathbf{C}_s;\theta_q) \\ w_1(\mathbf{C}_s;\hat{\theta}_{q',N}) - w_1(\mathbf{C}_s;\theta_{q'}) \end{bmatrix} \xrightarrow[N\to+\infty]{} \mathbf{N}\left(\mathbf{0}, \begin{bmatrix} \mathbf{W}_q'\Sigma_q\mathbf{W}_q & 0 \\ 0 & \mathbf{W}_{q'}'\Sigma_{q'}\mathbf{W}_{q'} \end{bmatrix}\right)$$

A simple Wald type test of:

$$\mathrm{H}_0 : w_1(\mathbf{C}_s;\theta_q) = w_1(\mathbf{C}_s;\theta_{q'}) \quad \textit{versus} \quad \mathrm{H}_a : w_1(\mathbf{C}_s;\theta_q) \neq w_1(\mathbf{C}_s;\theta_{q'})$$

can be constructed with the test statistic:

$$\hat{T}^{W,q,q'}_{Cs,N} \equiv \frac{\left[w_1(\mathbf{C}_s;\hat{\theta}_{q',N}) - w_1(\mathbf{C}_s;\hat{\theta}_{q,N})\right]^2}{\hat{\mathbf{W}}_{q,N}'\hat{\Sigma}_{q,N}\hat{\mathbf{W}}_{q,N} + \hat{\mathbf{W}}_{q',N}'\hat{\Sigma}_{q',N}\hat{\mathbf{W}}_{q',N}}$$

and its associated critical region at the α % confidence level:

$$\left\{\hat{T}^{W,q,q'}_{Cs,N} > \chi^2_{1-\alpha}(1)\right\}.$$

Note that the term:

$$\hat{\mathbf{W}}_{q,N}'\hat{\Sigma}_{q,N}\hat{\mathbf{W}}_{q,N} + \hat{\mathbf{W}}_{q',N}'\hat{\Sigma}_{q',N}\hat{\mathbf{W}}_{q',N}$$

is an estimator of the asymptotic variance of the estimator:

$$w_1(\mathbf{C}_s;\hat{\theta}_{q',N}) - w_1(\mathbf{C}_s;\hat{\theta}_{q,N})$$

of the share difference:

$$w_1(\mathbf{C}_s;\theta_q) - w_1(\mathbf{C}_s;\theta_{q'}).$$

Under the hypotheses that:

$$\left|w_1(\mathbf{C}_{s0};\theta_q) - w_1(\mathbf{C}_{s0};\theta_{q'})\right| \neq 0$$

and that $\left|w_1(\mathbf{C}_{s0};\theta_q)-w_1(\mathbf{C}_{s0};\theta_{q'})\right|$ decreases as s decreases starting from s_0, one can recover the choke price ratio r^c as:

$$r^c \equiv \underset{S}{Max}\left\{s \,/\, \hat{T}^{W,q,q'}_{Cs,N} \leq \chi^2_{1-\alpha}(1)\right\},$$

i.e., the highest value of s for which the test of H_0 is accepted at the α confidence level.

It should be noted that if r^c is very different from r, this estimated choke price ratio must be used with caution since it may be determined by using the estimated demand out of the domain where they can be considered as good approximations to the true one, i.e. out of the neighborhood of the point of approximation.

Figure 1. Bottled water consumption and price in France (French Francs 1980 per capita and deflated price indices in base 100 in 1980)

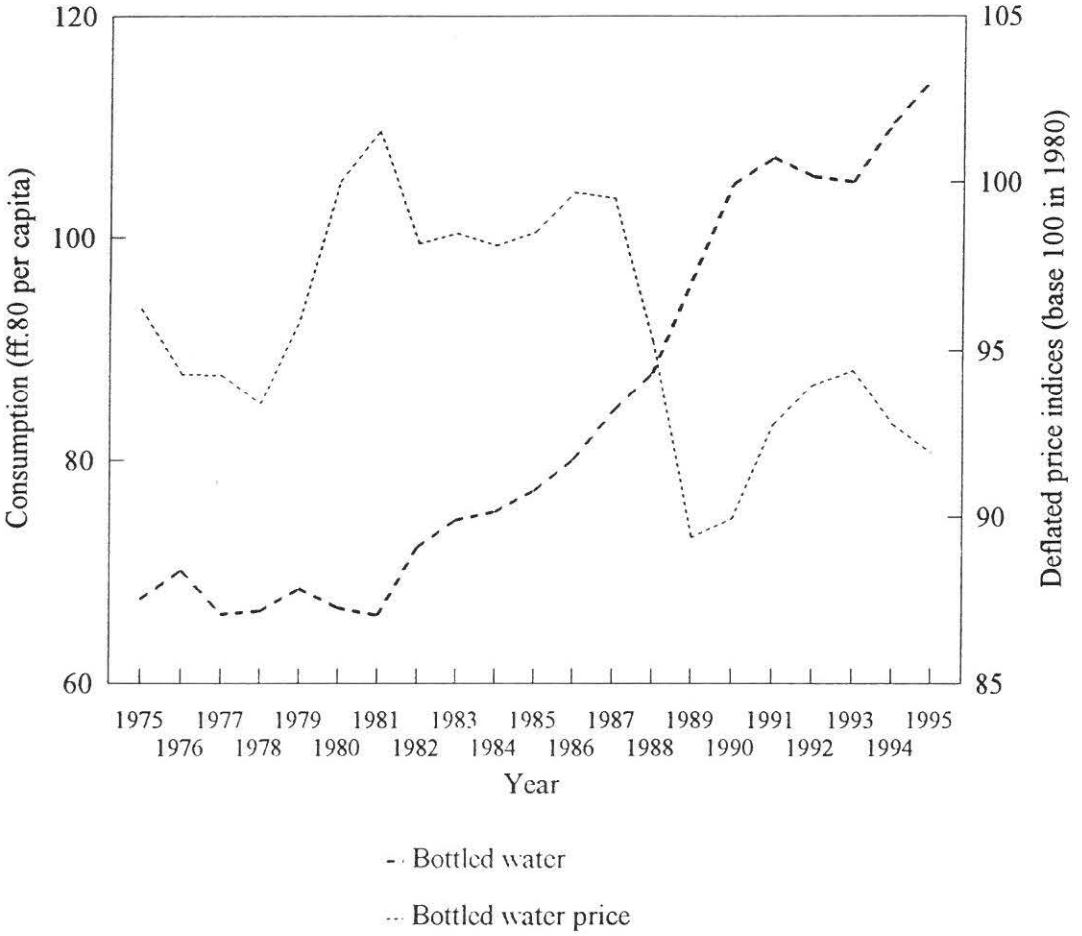


Figure 2. Areas of France defined according to presumed similarities and/or differences in tap water quality

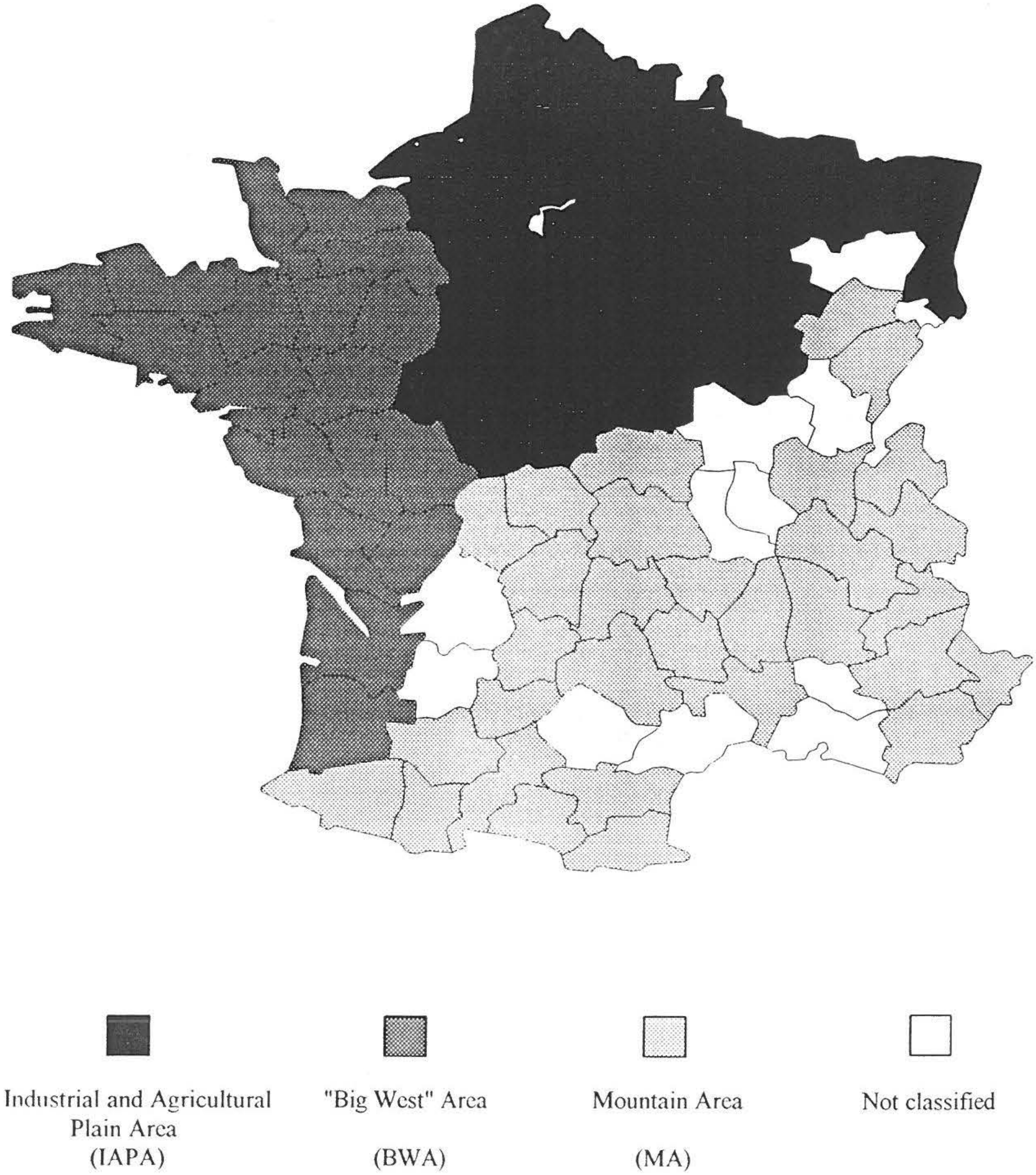


Figure 3a. Bottled water purchase mean in the Mountain Area (cl per household per week)

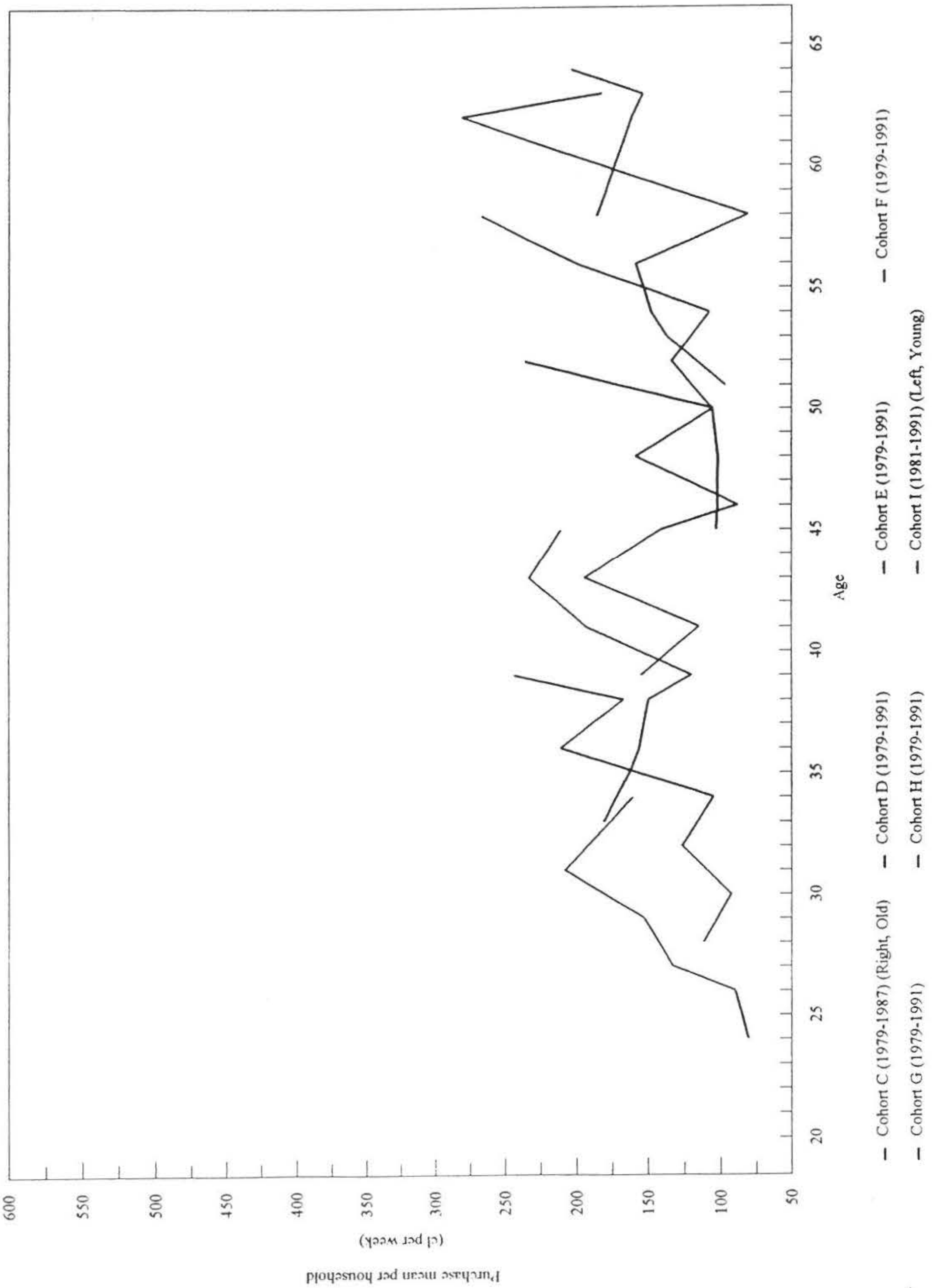


Figure 3b. Bottled water purchase mean in the Industrial and Agricultural Plain Area (cl per household per week)

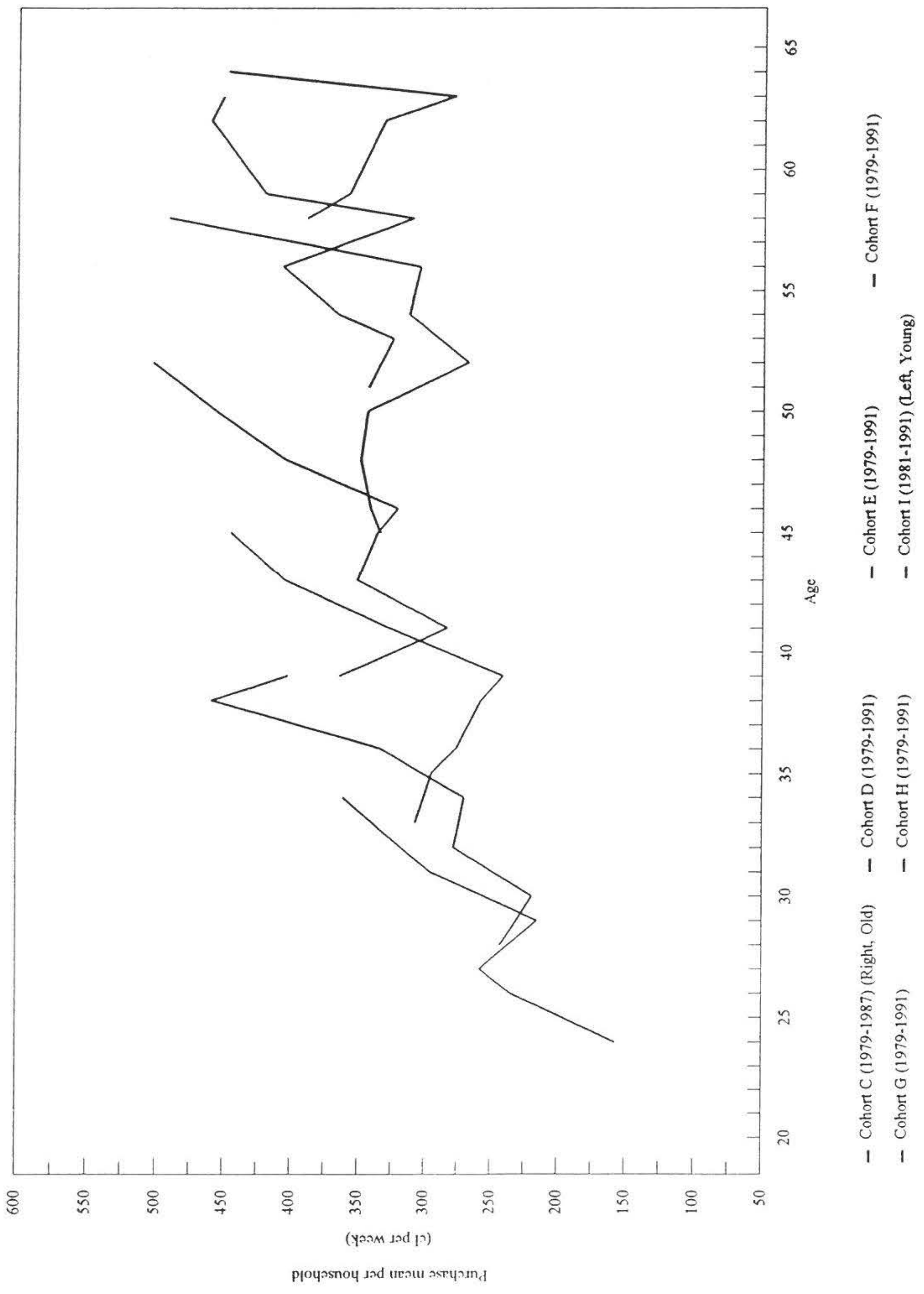


Figure 3c. Bottled water purchase mean in the "Big West" Area (cl per household per week)

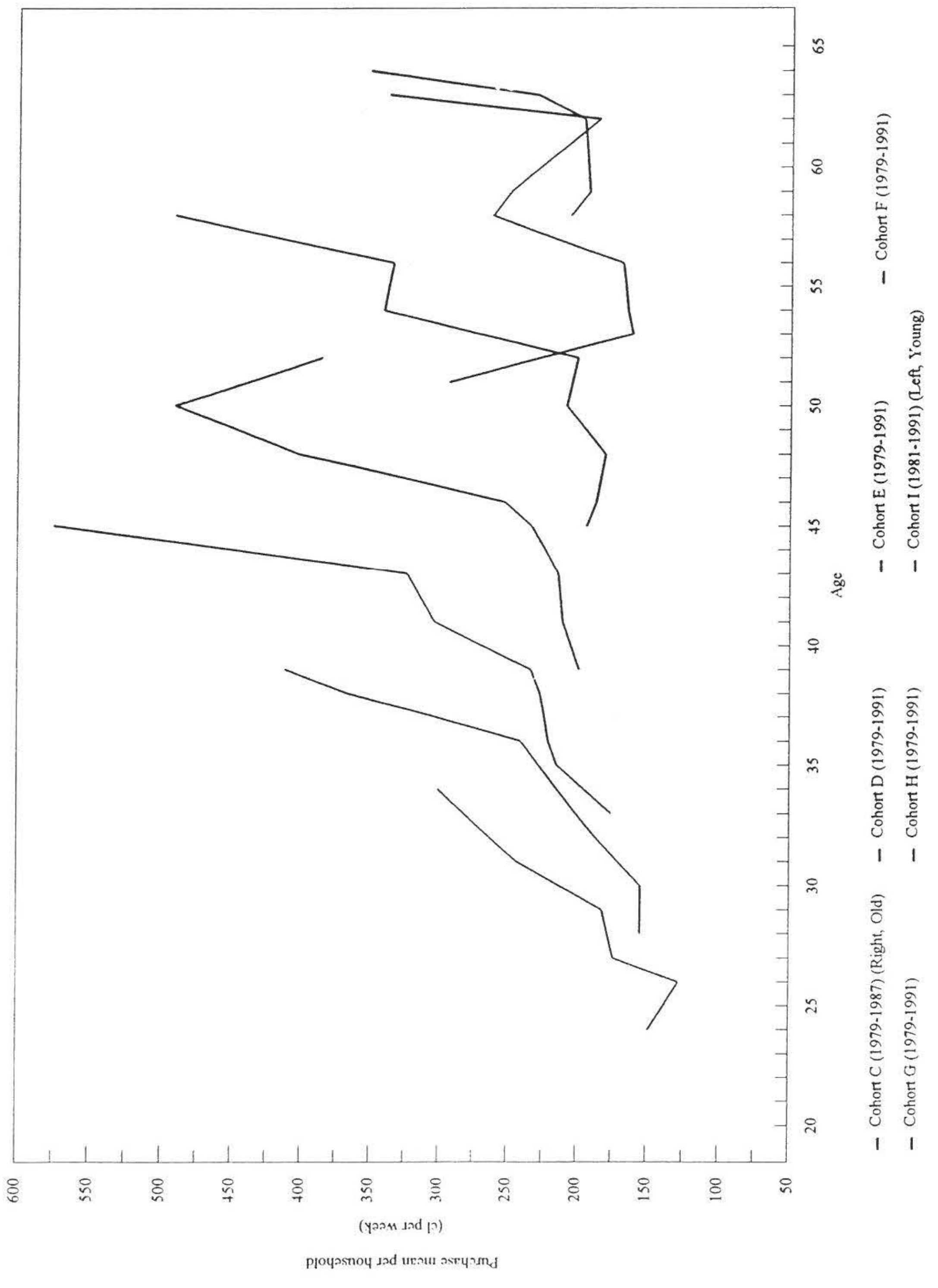


Figure 4a. Soft drink (excepted bottled water) purchase mean in the Mountain Area (cl per household per week)

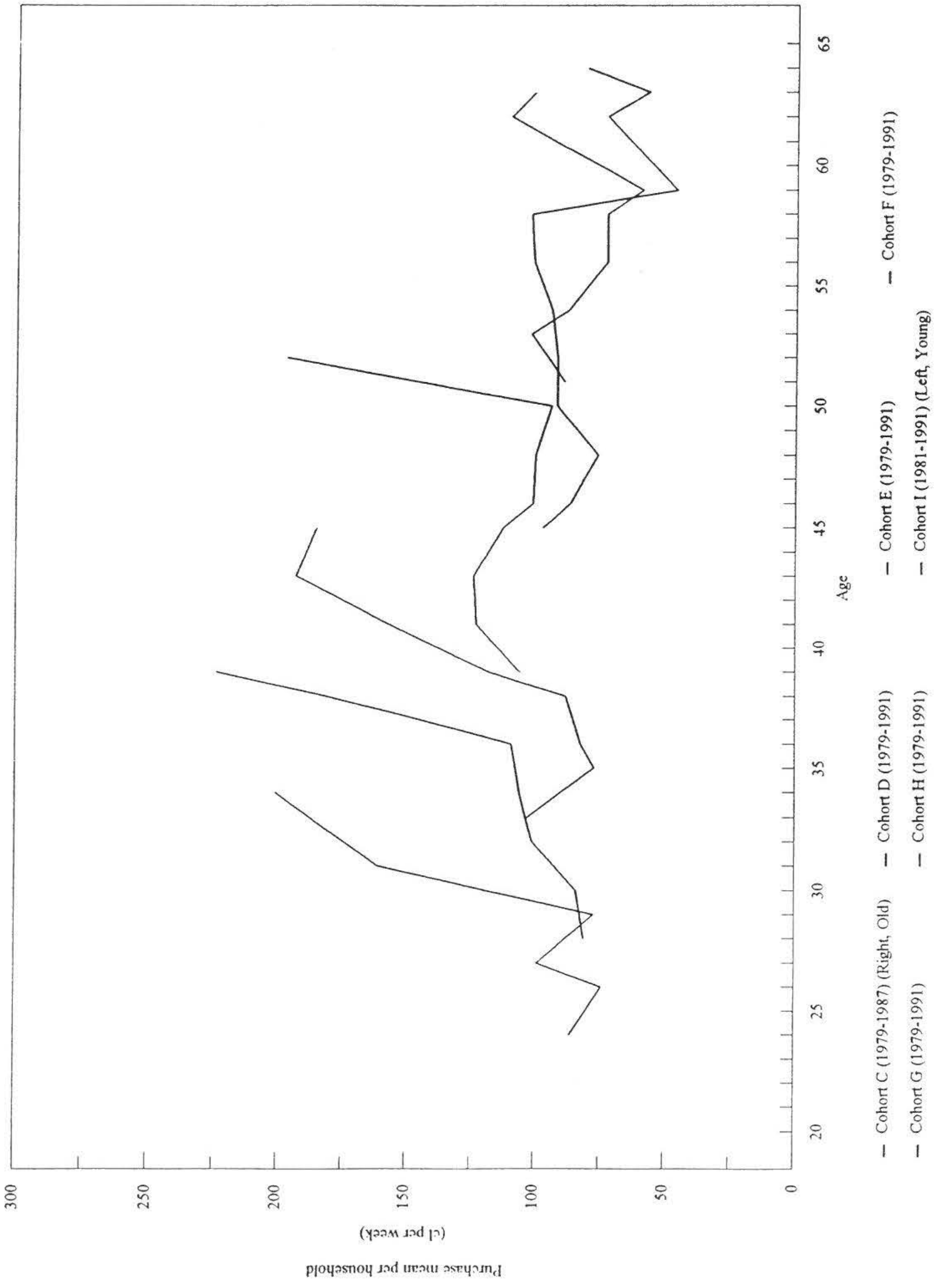


Figure 4b. Soft drink (excepted bottled water) purchase mean in the Industrial and Agricultural Plain Area (cl per household per week)

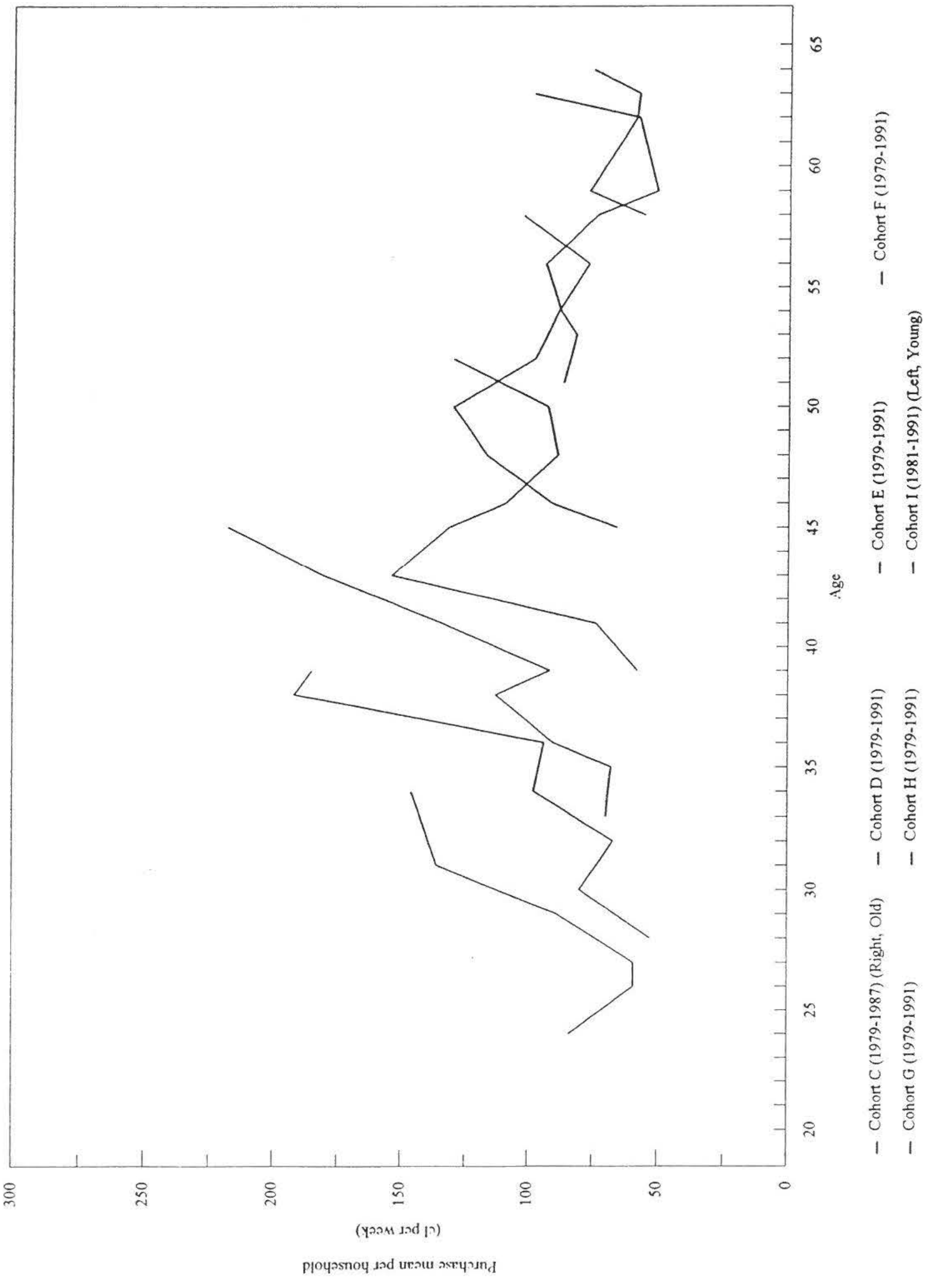


Figure 4c. Soft drink (excepted bottled water) purchase mean in the "Big West" Area (cl per household per week)

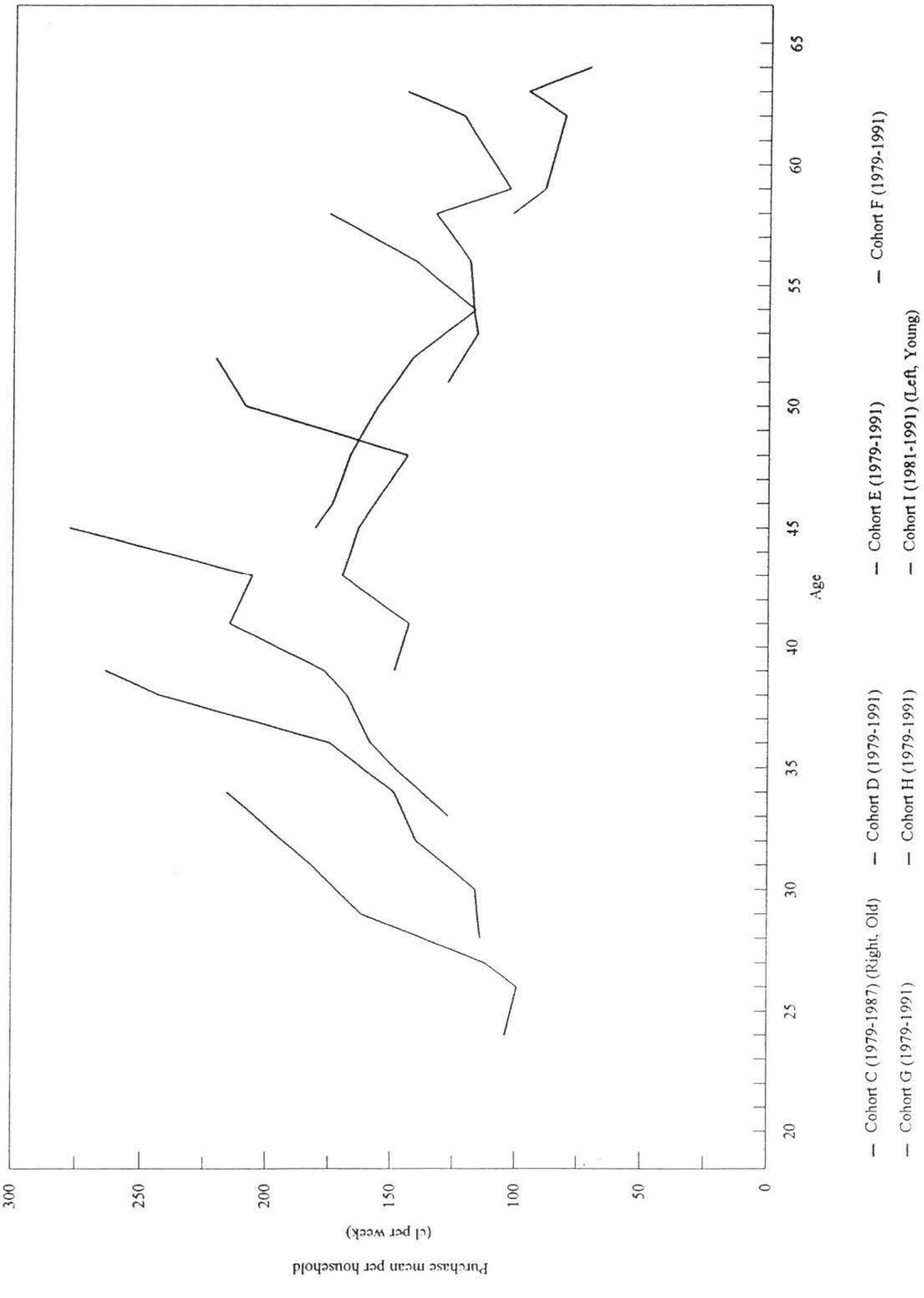


Figure 5. Soft drink consumption and price in France (French Francs 1980 per capita and deflated price indices in base 100 in 1980)

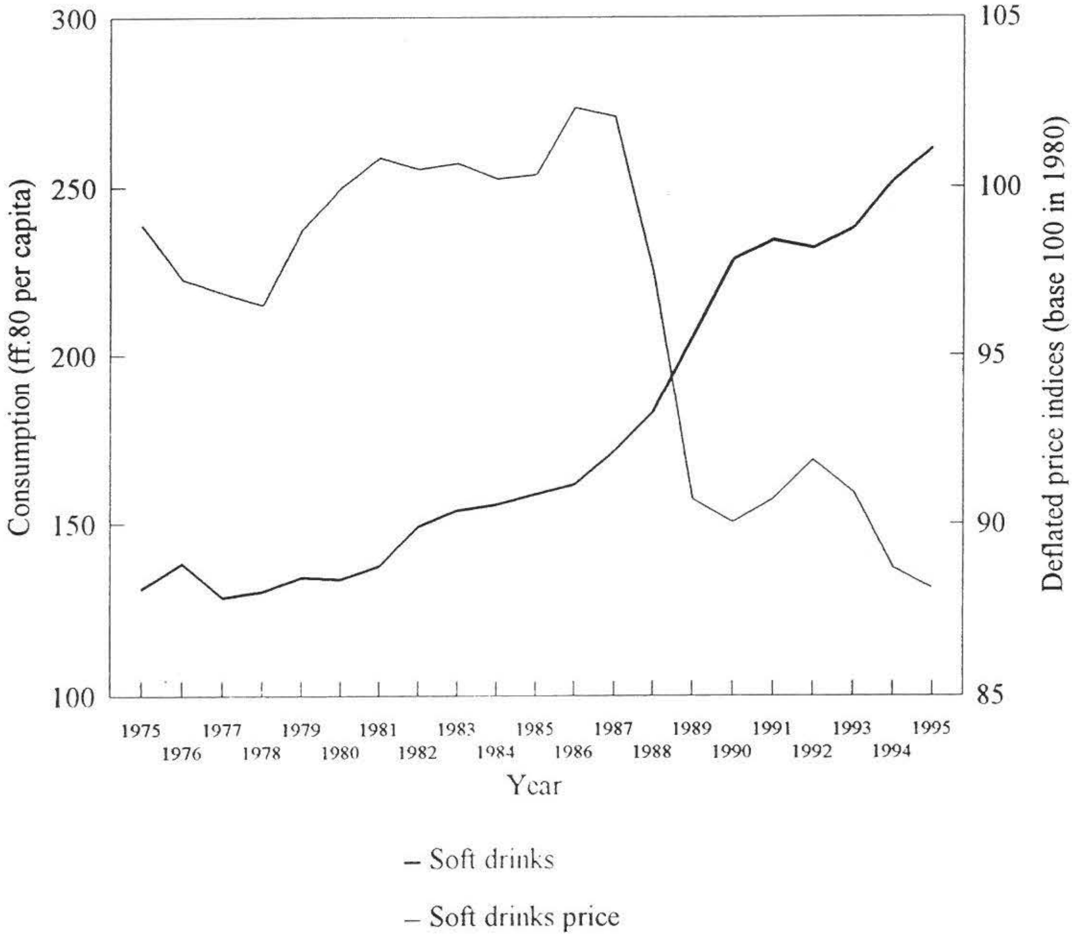
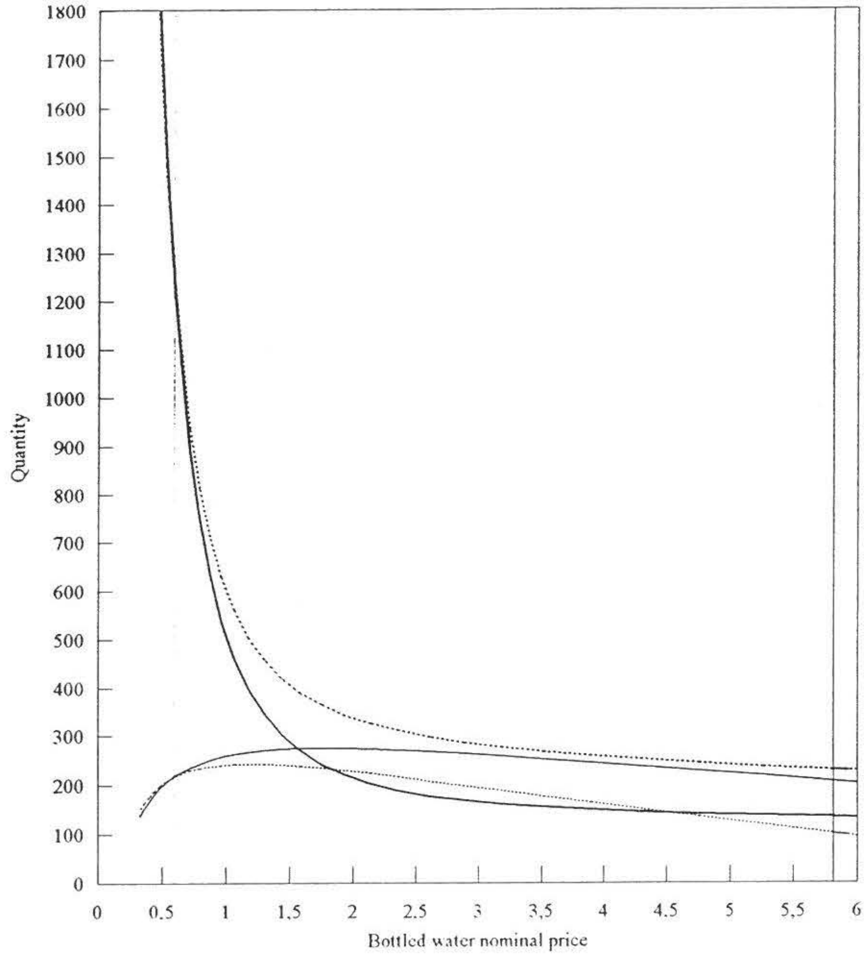


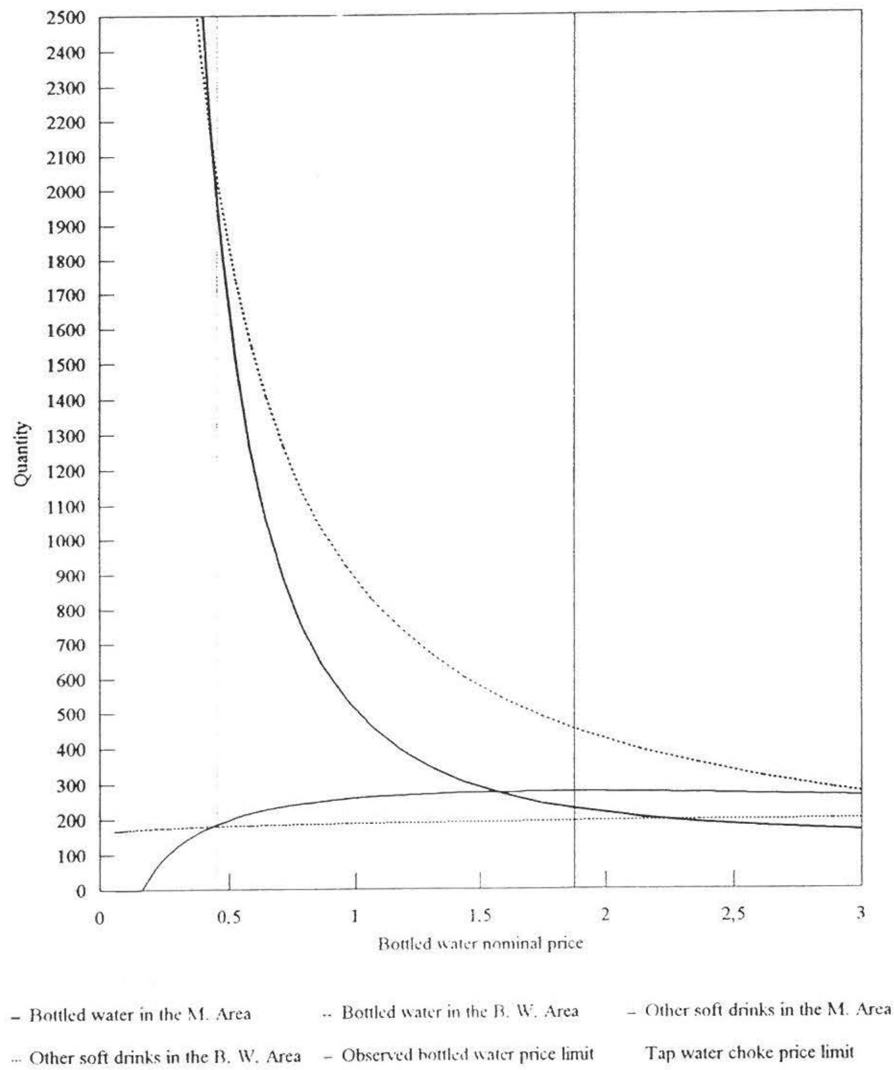
Figure 6a. Estimated Marshallian demands[a] for soft drinks as functions of bottled water price in the MA and in the IAPA (Quantities in cl per liter, price in French Francs 1991 per liter)



- Bottled water in the M. Area .. Bottled water in the I. A. P. Area - Other soft drinks in the M. Area
... Other soft drinks in the I. A. P. Area - Other soft drink price limit Tap water choke price limit

a. The considered household is composed of two adults and a child, the head is 40 years old. The demands are computed for a total soft drink expenditure equal to 15.5 FF 1991. The other soft drink price is equal to 5.80 FF 1991 per liter.

Figure 6b. Estimated Marshallian demands[a] for soft drinks as functions of bottled water price in the MA and in the BWA (Quantities in cl per liter, price in French Francs 1991 per liter)



a. The considered household is composed of two adults and a child, the head is 40 years old. The demands are computed for a total soft drink expenditure equal to 15.5 FF 1991. The other soft drink price is equal to 5.80 FF 1991 per liter.

Figure 7a. True cost of drinking in the IAPA, the reference state being the MA situation

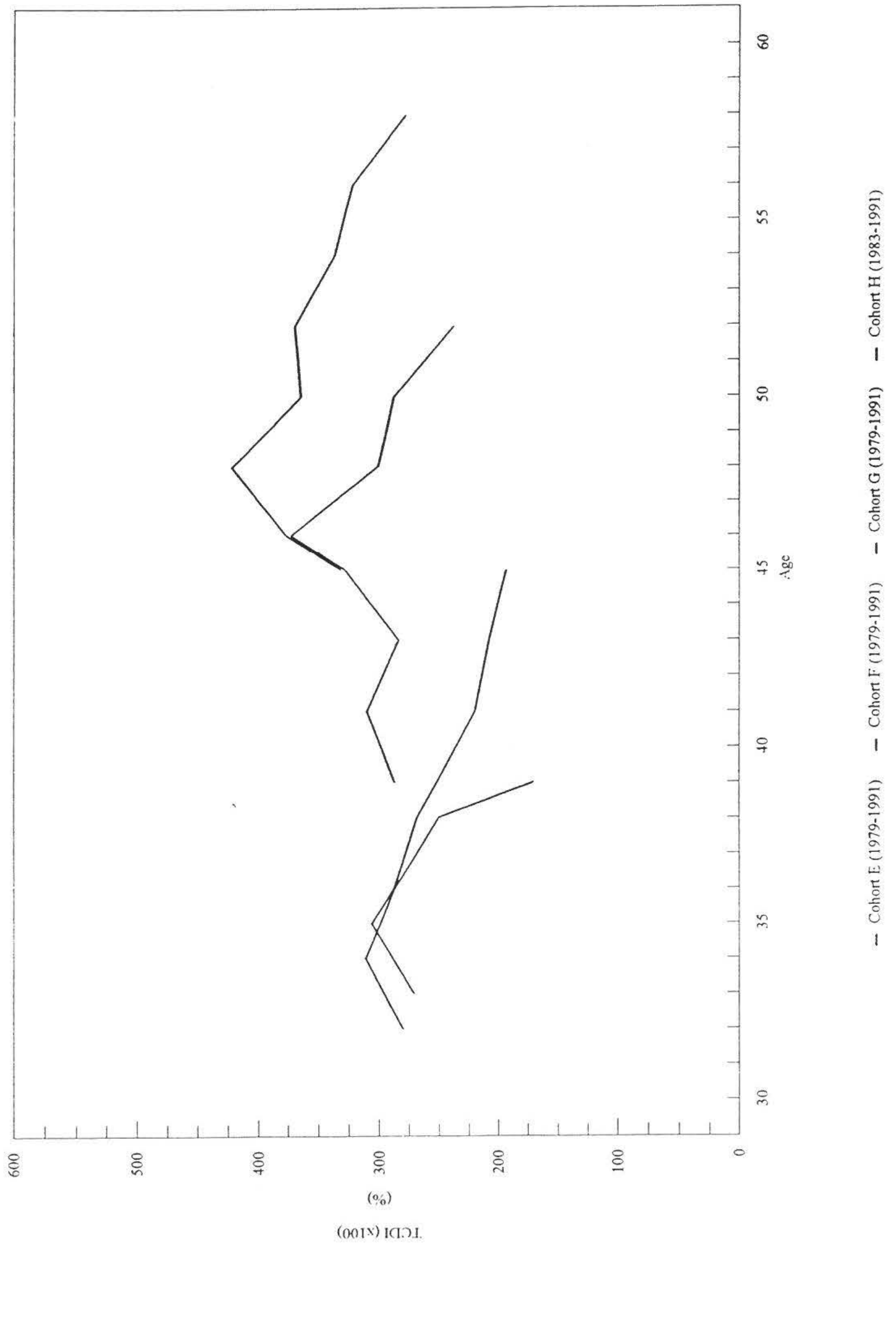


Figure 7b. True cost of drinking in the BWA, the reference state being the MA situation