*Nitrate pollution, perceived water quality, drinking water choice and water prices*

*A hybrid choice model*

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**Abstract:**

The way that consumers perceive the quality of drinking water in relation to nitrate pollution from agriculture may influence their main drinking water choice (tap water, filtered water or bottled water). Indeed, polluted tap water is associated with health risks. In addition, the literature usually discards the important price difference between bottled water and tap water as a predictor of drinking water choices. In France, which is the context of our study, bottled water is about 100 times more expensive than tap water. In this paper, we use a dataset of about 4,000 individuals, which is rich enough to allow us not only to assess how drinking water choices are associated with the perceived quality of water resources but also with the perceived price difference between bottled water and tap water. We use a hybrid choice model framework where we jointly model drinking water choices together with the perception of tap water in terms of quality and price. These models are interacted by the means of two latent variables which alleviates some of the endogeneity issues which are usually found in the literature on drinking water choice. Our results suggest that respondents who are more likely to report the quality of water resources as "poor" or "very poor" are less likely to drink tap water and that the respondents who fail to report the correct price difference between tap water and bottled water are more likely to drink bottled water.

Keywords: drinking water choice; nitrate pollution; hybrid choice model; perception variables, endogeneity

JEL codes: C35, D12, L95, Q25, Q51, Q53

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## Introduction

It is well-known that agriculture is the source of multiple negative externalities on the environment, including air pollution, wetland degradation, biodiversity loss as well as surface water and groundwater pollution. Nitrate from farming is found to be the most common contaminant in groundwater worldwide (WWDR, 2019). In countries where tap water is produced mainly from groundwater, individual knowledge and perception of water resources quality, in relation to nitrate pollution from agriculture, may actually influence drinking water choices (tap water, filtered water, bottled water). Choosing filtered or bottled water over tap water can be interpreted within the framework of averting-behavior models (Lanz and Provins, 2017).

In the literature on tap water consumption, many authors have used answers to attitudinal statements directly as covariates in a drinking water choice model (Bontemps and Nauges, 2016). However, it is now widely acknowledged that attitudes and perceptions are unobserved and that only manifestations or imperfect measurements of these attitudes can be observed (Hess *et al.*, 2013). More precisely, the *perceived quality of water resources* is arguably not an exact measure of the way respondents perceive it, but a function thereof, and using it as an explanatory variable in a model of drinking water choice is hence likely to put the analyst at risk of measurement error. Moreover, the likely correlation between such an indicator and other unobserved factors within a choice model can lead to serious endogeneity bias (Hess and Stathopoulos, 2013). It is now common place in the choice modeling literature to handle such issues by the means of hybrid choice models (Ben-Akiva *et al.*, 2002), where attitudinal and perceptual statements are treated as indicators of one or several latent variables and where the value of the indicators is modeled jointly with the actual choice(s), based on the assumption that both processes are (at least partially) influenced by the same latent variables. Hess and Stathopoulos (2013) note that the general use of attitudinal data as explanatory variables in discrete choice models is being increasingly abandoned in favor of latent variable models such as the hybrid choice model (see also Roberts *et al.*, 2018 for a recent application showing the influence of environmental perception variables on daily commute choices).

In this paper, we propose to explore the relationship between individual perception of water resources quality (surface water and groundwater) and drinking water choices using a hybrid choice model. To this end, we use a unique database of 4,003 individuals surveyed in France in 2013 about their perception of water resources and their drinking water choice. In relation to our objective, the use of this database has two main advantages. Firstly, 64% of the tap water produced in France comes from groundwater resources, and 65% of the individuals surveyed consider agriculture to be the main source of nitrate pollution (CGDD 2012, 2014); nitrate pollution from agriculture is common knowledge in France, which strongly suggests that individual perceptions of water resource quality are influenced by actual levels of nitrate (most likely at the local level). Secondly, the survey also featured questions regarding how individual perceive the price difference between tap water and bottled water. Such a piece of information is usually not available to analysts and allows us to propose a more complete model than those usually found in the empirical literature on drinking water choices, integrating both *the perception of water resource quality* and *the perception of the price difference between bottled and tap water*.

The rest of the paper is organized as follows. In the next section, we give an overview of nitrate pollution from agriculture in France. Then we return to the role of environmental quality perception, and the specification of water price in the empirical literature on drinking water choices and residential water demand. We describe the data in the following section. Then we present in detail the hybrid choice model, and the estimation results. The final section concludes.

**Nitrate pollution from agriculture in France**

France is the leading European country in terms of agricultural production (18% of total European production). Agricultural activities use nitrogen fertilizers produced by industry (inorganic nitrogen fertilizers) but also fertilizers produced from livestock, for example manure. According to the *French Commissariat Général au Développement Durable* (CGDD), 1.5 million tons of nitrates are released into the environment every year in France (soil, water and air). This represents nearly 32 kilograms (kg) of nitrates per hectare of agricultural land (CGDD, 2015). According to the French Agency for Biodiversity (ONEMA, 2016), the nitrate concentration of 49% of the groundwater catchments for drinking water supply in France have been found to have a nitrate concentration ranging from 0 to 25 milligrams per liter (mg/l) in 2014. For 38% of the water catchments tested, the nitrate concentration ranged from 25 mg/l to 50 mg/l. Finally, 13% of the catchments tested exceeded the maximum authorized threshold of 50 mg/l established by the two European framework directives on nitrates (1991) and water policy (2000). Concerning surface water, only 4% of the catchments had a concentration level higher than 40 mg/l and more than 80% of the catchments had a concentration level lower or equal to 25 mg/l. While groundwater pollution by nitrates is more significant than for surface water, it is the main source of water for drinking water supply, since 64% of tap water in France is produced from groundwater (CGDD 2012). Thus, and although raw water treatment allows the French to drink tap water that is safe from a health point of view, nitrate nitrogen residues cannot be completely removed from water intended for human consumption. Nitrate contamination of water exposes individuals to various health risks, of which the most well-known is methemoglobinemia, also known as the "blue-baby syndrome", but also cancers including gastric cancer (Jordan and Elnagheeb, 1993).

**Perception of water pollution and drinking water choices in the literature**

The first article using French data and whose central question concerns drinking water choices is that of Bontemps and Nauges (2009). The authors show that environmental and socio-demographic factors influence the choice of whether or not to drink tap water. More specifically, environmental quality, measured by a "poor raw water quality index", has a negative effect on the probability of drinking tap water (the marginal effect is estimated at -0.63). Wealthier households and households headed by retired individuals are found to have a relatively higher preference for the consumption of bottled water. The main limitation of this study is that the authors constructed the drinking choice variable *ex post*. They considered that individuals who bought less than 0.5 liters of soft drinks per day were tap water drinkers. A sensitivity test on this threshold, reduced to 0.2 liters, leads to a questioning of the main result, as the poor quality index of raw water no longer appears as a significant predictor of drinking water choice.

Two other articles use French data although France is not the focus of their analysis. Given the fact that the drinking water supply system is managed efficiently in most developed countries (no interruption to drinking water supply, high physicochemical compliance levels), Johnstone and Serret (2012) study the determinants of bottled and filtered water consumption. The authors use a sample of 10,000 households from 10 OECD countries, including France, and report that the choice of households to consume tap water over filtered or bottled water is influenced by their perception of the health risks associated to tap water consumption, organoleptic factors (e.g., odor and color) of tap water, as well as socio-demographic factors (income, household size, presence or absence of children in the household). They estimate a simple multinomial logit (without modeling unobservable heterogeneity) with fixed effects for each country considered. Although they use attitudinal variables in their work, these authors do not control for endogeneity. On the other hand, endogeneity is at the heart of the paper by Bontemps et Nauges (2016). The authors compare the results of a recursive bivariate probit model with a special regressor approach model, the latter relying on less demanding distributional assumptions. Empirically, their work focuses on the decision to drink tap water or not, one of the predictors of which (likely to be endogenous) is the level of satisfaction regarding tap water. They use a sample of 2,635 individuals from two OECD surveys conducted respectively in 2008 and 2011, selecting three countries from those surveyed: France, Australia and Canada. Controlling endogeneity through the "special regressor" approach, Bontemps and Nauges (2016) show that the marginal effect of the attitudinal variable on individual satisfaction with tap water is twice as small as with the recursive bivariate probit approach. However, like Johnstone and Serret (2012), the heterogeneity of individual preferences is not modeled.

For the United States, Abrahams, Hubell and Jordan (2000) focus on drinking water choices in the state of Georgia. Using a simple multinomial model, they highlight the role of reports given by local authorities when an incident concerning the supply or quality of tap water arises, organoleptic factors, the perceived risk of consuming poor quality tap water, as well as socio-economic factors on drinking water choice (tap water, filtered tap water or bottled water). Regarding bottled water, their conclusions are as follows:

- The marginal effect of organoleptic factors on the probability of drinking bottled water is about 0.23 percentage points, indicating that households prefer to drink bottled water when the taste of tap water is too strong or when it is perceived that tap water has an odor or a color;
- The marginal effect of the perceived risk is about 0.18 percentage points. As people's satisfaction with tap water declines, they prefer to drink bottled or filtered tap water to avoid health risks;
- Finally, only age and ethnicity are significant socio-economic factors. The older respondents are , the most likely they are to drink tap water; moreover, when an individual belongs to an ethnic minority, it increases the probability that she/he drinks bottled water.

Regarding the decision to use a domestic filtration system, the significant variables are information, with a marginal effect on the probability of drinking filtered water of about 0.13, risk perception (0.07) and income (0.002). It should be noted that Abrahams, Hubell and Jordan (2000), while acknowledging that risk perception is probably endogenous, face the absence of data regarding objective risk measure and ultimately assume, for the empirical part of their work, that objective risk and perceived risk are identical.

Viscusi *et al*. (2015) show from a sample of 1,008 American individuals and the estimation of probit and SUR (Seemingly Unrelated Regression) models that the belief that bottled water is better for health than tap water, the taste of bottled water is better than tap water and past bad experiences with tap water (bad taste, unpleasant smell) are major determinants of drinking water choice. In addition, ethnic minority status, income level and being a woman have a positive and significant impact on the decision to drink bottled water. Doria (2006) finds similar results, and more particularly that the choice to consume bottled water, although it is a relatively more expensive good than tap water, is influenced by organoleptic factors (mainly taste) and by concerns about health safety.

At last, based on Canadian data, Lloyd-Smith *et al.* (2018) found with a latent class model that perceived risk negatively affects the probability of drinking tap water. Their focus, however, is on the issue of defensive expenditures against the health risks associated with tap water consumption.

**Water price as a predictor of drinking water choice**

In order to empirically explore the mechanisms that govern drinking water supply choices, the use of a price variable seems both intuitive and clearly theoretically grounded: the residential water demand can be derived from a maximization problem where the water price plays a central role (see, e.g., Vásquez Lavín *et al.*, 2017).

However, the type of tariff structure, especially the case of increasing or decreasing block tariffs (a fixed charge plus marginal prices based on quantities consumed), requires the modeler to consider the type of price to be used in the estimates. Three types of prices are mainly used by economists to explore and estimate residential water demand functions, namely the average price, the marginal price and other price specification such as Nordin's difference variable or Shin's price perception variable (Taylor, 1975; Nordin, 1976; Shin, 1985).

Used in one-third of the work between 1963 and 2013 on the water demand function (Marzano *et al.*, 2018), the average price is calculated as the ratio between the water invoice and the quantity of water consumed (Wong, 1972; Foster and Beattie, 1980; Renwick and Green, 2000; Schleich and Hillenbrand, 2009). However, as Nauges and Reynaud (2001) point out, the marginal price is to be preferred to the average price since consumer theory is based on the "principle of equalizing the marginal surplus to the marginal cost". Econometrically, when the average price is used, this results in a simultaneity bias. In other words, it triggers an endogeneity issue since water consumption appears on both sides of the demand equation (Bachrach and Vaughan, 1994; Nauges and Reynaud, 2001 and Ayadi *et al.*, 2003). Of course, endogeneity can be addressed by appropriate instrumental variable methods and/or appropriate functional forms, but ultimately the relevant price elasticities (in terms of policy recommendations) are not easy to assess (see Vásquez Lavín *et al.*, 2017).

The second type of price used in empirical studies is the marginal price (for 52% of the works between 1963 and 2013; see Marzano *et al.*, 2018). The use of the marginal price is consistent with consumer theory (Nauges and Reynaud, 2001) since it is defined as the price of the last unit consumed. Howe and Linaweaver (1967) were the first to use it in their work, the objective of which was to demonstrate the value of individual water meters for effective household resource management, particularly through price.

Nordin (1976) proposes to take into account the infra-marginal nature of increasing block tariffs by introducing a "difference" variable. This variable corresponds to the difference between "what the economic agent actually pays and what he would have paid if all units had been billed at the marginal price of the last unit consumed" (Nauges and Reynaud, 2001). The difference variable is used to control for the income effect associated with discontinuous tariffs structure (Marzano *et al.*, 2018). As a result, the explanatory variable related to the difference should be equal, with the opposite sign, to the income coefficient. However, many studies have failed to verify these results with data (Renwick and Green, 2000; Martinez-Espiñeira, 2002; Carter and Milon, 2005).

Shin (1985), in the context of electricity consumption, shows that users tend to use a "perceived (marginal or average) price" because it would be too difficult for them to determine the price actually paid. Three reasons are given for the fact that users govern in relation to the perceived price and not the actual price (marginal or average price). First of all, the block tariff structure is often ignored by users (which is true in the French case, see below), which leads them not to know the difference between average and marginal prices and ultimately to not know its effects on consumption. Second, even with perfect information, it is difficult to react immediately to price changes. Users would only adjust their consumption after receiving an invoice for the billing period. Finally, for residential drinking water, it seems unlikely that consumers actually know how to separate the share of the bill for residential drinking water from that of the sanitation service, taxes and charges. In their meta-analysis of the price response to residential water tariffs, Marzano *et al.* (2018) report that about 2.4 % of the empirical studies they have collected use Shin's water price specification.

To conclude, regardless of the price used (marginal or average, other specifications), empirical research shows that residential water consumption is price-inelastic (Sebri, 2014, Marzano *et al.*, 2018). Additionally, the literature review shows that the empirical analysis of averting behaviors for water quality considered bad or very poor, whether based on protection expenditures or drinking water choices, requires to control for the endogeneity of attitudinal variables (quality perception and/or price perception, see Lloyd-Smith *et al.*, 2018). In addition, the perception of water quality is closely related to the health risk perceived by individuals. In other words, since nitrate pollution from agriculture is common knowledge in France, it is relevant to look at the links between the individual perception of water resource quality, actual nitrate pollution from agriculture and drinking water choices.

In line with Shin's (1985), we consider that individuals would eventually react to a perceived price and not to an objective price. Indeed, in the French case, only 20% of consumers have an almost correct knowledge of the tap water price and 60% even state they don't know at all the tap water price (CGDD, 2014). It is then obvious that consumers do not use any objective water price variable in the utility maximization process underlying their drinking water choices. However, as it will be argued later in this article, the perceived difference in water prices (bottled water, tap water), may actually play a significant role in individual drinking water choice. Before turning to the econometric strategy, we now present the data in detail.

**Data**

The data come from a survey conducted in 2013 by the Institut Français d'Opinion Publique (IFOP) on behalf of the *Service de l'Économie, de l'Évaluation et de l'Intégration du Développement Durable* (SEEIDD) of *the Commissariat Général au Développement Durable* (CGDD, 2014). The full sample consists of 4,003 individuals, aged from 18 to 90 years. The representativeness of the sample is ensured by the quota method with respect to the criteria of gender, age, occupation, urban area categories, region and housing occupation status, all based on data from the 2010 INSEE census. The database includes a set of variables related to drinking water consumption patterns and socio-economic characteristics of individuals. We supplemented it with exogenous variables on the level of pollution of raw water (nitrate concentration in groundwater by geographical district) as well as on the average regional and departmental rainfall. These variables are taken from the Eider database of the Ministry for the Ecological and Inclusive Transition, as well as from the public water data web portal (data.eaufrance.fr).

In the survey, the question regarding the choice of the main mode of drinking water consumption was worded as follows:

"At home, when you drink water, most often you drink...?

(Only one answer possible)

- Mostly bottled water,
- Mainly filtered tap water,
- Mostly tap water."

*Descriptive statistics*

Since income is a common feature of the work discussed in the literature review, we first excluded, in order to compare our results with previous results, observations for which this variable was missing, which reduces the sample size used for the estimates to 3,506 individuals. The main descriptive statistics for the full sample and the estimation sample are presented in Table 1. The characteristics of the two samples are very similar. As long as the representativeness of the full sample was corroborated (CGDD, 2014), the representativeness of the estimation sample is therefore not an issue. In the following, the statistics presented refer to the estimation sample.

**Table 1. Descriptive statistics**

| Variables | Mean | |
|---|---|---|
| | Full sample | Estimation sample |
| Bottled water | 39% | 39% |
| Filtered water | 21% | 21% |
| Tap water | 40% | 40% |
| Age | 47 years old | 47 years old |
| (standard deviation) | (16) | (16) |
| Gender (Woman) | 52% | 51% |
| Degree | | |
| *No degree* | 3% | 3% |
| *Middle school degree* | 26% | 26% |
| *High school degree* | 19% | 19% |
| *Bachelor degree* | 24% | 24% |

| | | |
|---|---|---|
| *Master and higher degree* | 19% | 19% |
| Rural housing (less than 2,000 inhabitants) | 23% | 23% |
| Average monthly income | - | 2,759€ |
| (standard deviation) | - | (1,658) |
| Number of children | 0.521 | 0.526 |
| Occupancy status | | |
| *Owner* | 63% | 63% |
| *Tenant* | 37% | 37% |
| Number of observations | 4,003 | 3,506 |

*Source: Authors' calculations*

The main drinking water choice in France (Table 1) is tap water (40.44%). Bottled water is the second most popular (38.59%). Finally, filtered water comes in third place and is consumed by 20.96% of the individuals sampled.

*Drinking water choice and perceived quality of water resources*

Does the drinking water choice depend on the perceived quality of the water resource, measured by the level of satisfaction with the water resource stated by individuals[1]? The level of satisfaction with the quality of the water resource can take one value among four: very poor, poor, fair and very good. As a first step in our analysis, we report the choice of drinking water depending on the perceived quality of the water resource (Table 2). We can observe that the share of tap water consumers is 34.34% when individuals consider that the water resource is of very poor quality while it increases to 53.90% when they consider it to be very good, (an increase of 19.56 percentage points). The dependence between the two variables, one nominal, the other ordered, is confirmed by a $\chi^2$ test ($\chi^2$ (6) = 45.1451, *p-value* = 0.000).

**Table 2. Drinking water choice and perceived quality of water resources**

| | Bottled water | Filtered water | Tap water |
|---|---|---|---|
| Very poor | 44.44% | 21.21% | 34.34% |
| Bad | 45.36% | 20.20% | 34.45% |
| Good | 35.61% | 21.46% | 42.93% |
| Very good | 26.95% | 19.15% | 53.90% |

[1] In response to the following question: "Apart from drinking water, would you say that the quality of water in France (whether in rivers, lakes, groundwater) is...?"

*Source: Authors' calculations*

*Drinking water choice and geographical location*

The survey groups individuals into eleven French regions:

- Auvergne-Rhône-Alpes
- Bourgogne-Franche-Comté
- Bretagne
- Centre-Val de Loire
- Grand Est
- Hauts-de-France
- Île-de-France
- Normandie
- Occitanie
- Pays de la Loire
- Provence-Alpes-Côte d'Azur et Corse

**Table 3. Drinking water choice and geographical location**

| | Drinking water choice | | |
|---|---|---|---|
| | Bottled water | Filtered water | Tap water |
| Auvergne-Rhône-Alpes | 24.12% | 18.97% | 56.91% |
| Bourgogne-Franche-Comté | 37.65% | 17.90% | 44.44% |
| Bretagne | 44.51% | 22.53% | 32.97% |
| Centre-Val de Loire | 40.38% | 30.77% | 28.85% |
| Grand Est | 45.83% | 21.15% | 33.01% |
| Hauts-de-France | 61.46% | 20.70% | 17.83% |
| Île-de-France | 42.45% | 18.40% | 39.15% |
| Normandie | 40.57% | 28.00% | 31.43% |
| Nouvelle-Aquitaine | 34.74% | 22.36% | 42.90% |
| Occitanie | 29.24% | 19.88% | 50.88% |
| Pays de la Loire | 36.60% | 23.20% | 40.21% |
| Provence-Alpes-Côte d'Azur + Corse | 29.82% | 18.91% | 51.27% |

*Sources: Authors' calculations*

The regions of the South of France are the regions where individuals drink tap water the most (Auvergne-Rhône-Alpes: 56.91%; Provence-Alpes-Côte d'Azur and Corsica: 51.27%; Occitanie: 50.88%). On the other hand, the Hauts-de-France (17.83%), Centre-Val de Loire (28.85%) and Normandie (31.43%) are the regions where individuals drink tap water the least.

*Drinking water choice, water resource quality and socio-demographic variables*

From Table 4, we can identify several trends: the perception of the quality of water resources improves with age and is different across genders (women appear less satisfied than men). The higher the income, the more people have a good opinion of the quality of the water resource. Finally, tenants are less satisfied than homeowners.

**Table 4. Perceived water quality and socio-demographics variables**

| Perceived water quality | Age | Gender | Income | Degree (median class) | Tenant |
|---|---|---|---|---|---|
| Very poor | 42.84 | 0.56 | 2,371 € | Bac +1, +2, +3 | 0.53 |
| Bad | 44.37 | 0.57 | 2,566 € | Bac +1, +2, +3 | 0.43 |
| Good | 49.52 | 0.49 | 2,861 € | Bac +1, +2, +3 | 0.33 |
| Very good | 48.97 | 0.32 | 3,000 € | Bac +1, +2, +3 | 0.43 |

*Source: Authors' calculations*

Similarly, the cross-tabulation of drinking water choices and socio-demographic variables (Table 5) shows that bottled water consumption increases with age and income, while the effect of gender and housing occupation status is not clear.

**Table 5. Drinking water choice and socio-demographics variables**

| Drinking water choice | Age | Gender | Income | Degree (median class) | Tenant |
|---|---|---|---|---|---|
| Bottled water | 48.42 | 0.52 | 2,755 € | Bac +1, +2, +3 | 0.39 |
| Filtered water | 48.10 | 0.49 | 2,889 € | Bac +1, +2, +3 | 0.30 |
| Tap water | 46.75 | 0.51 | 2,695 € | Bac +1, +2, +3 | 0.39 |

*Sources: Authors' calculations*

*Nitrate concentration in raw water and geographical location*

**Table 6. Nitrate concentration in raw water and geographical location**

| | Average nitrate concentration |
|---|---|
| Auvergne-Rhône-Alpes | 13.56 |
| Bourgogne-Franche-Comté | 14.57 |
| Bretagne | 28.70 |
| Centre-Val de Loire | 19.93 |
| Grand Est | 16.53 |
| Hauts-de-France | 23.58 |
| Île-de-France | 10.20 |
| Normandie | 26.13 |
| Nouvelle-Aquitaine | 12.63 |
| Occitanie | 14.82 |
| Pays de la Loire | 20.89 |
| Provence-Alpes-Côte d’Azur + Corse | 8.13 |

*Sources: Authors’ calculations*

Table 6 reports the concentration of nitrates in milligrams per liter (mg/l) in the groundwater used for supplying drinking water. The regions with the highest nitrate concentration are Bretagne (28.70 mg/l), Normandie (23.58 mg/l) and the Hauts-de-France (23.58 mg/l). On the other hand, the Provence-Alpes-Côte d'Azur and Corse regions (8.13 mg/l), Île-de-France (10.20 mg/l) and Nouvelle-Aquitaine are the regions with the lowest concentration rates.

Finally, the survey shows that 80% of the population does not know the price of tap water; only 20% of the population seems able to indicate a value in line with the price actually charged (about €3.4 per m3). Additionally, in France, the price difference between tap and bottled water (bottled water is between 33 and 245 times more expensive than tap water, CGDD, 2014) is underestimated by about half the population, with 27% unable to comment on the difference. It is therefore likely that whether an individual correctly perceives the price difference between tap water and bottled water influences whether they choose to consume bottled water. Hence, our econometric strategy consists in modeling the perception of the value of tap water with respect to bottled water as a latent variable, where the stated perception of the price difference between bottled water and tap water is used as an indicator jointly estimated together with the choice model.

## Econometric Strategy

### Latent variables and hybrid choice model

*Basic model*

Based on Train's (2009) crystal-clear presentation, in a basic discrete choice model, the utility that an individual, noted *i*, derives from choosing alternative *j* from a set of *J* alternatives is:

$$U_{ij} = V_{ij} + \varepsilon_{ij} = \beta x_{ij} + \varepsilon_{ij}$$

where $x_{ij}$ is a vector of observed characteristics of alternative *j* and observed characteristics of individual *i* and $\beta$ a vector of coefficients, which are interpreted as weights in the utility function. $V_{ij} = \beta x_{ij}$ is often referred to as the deterministic component of the utility $U_{ij}$. The error term, $\varepsilon_{ij}$, captures the effect of variables that influence the utility $U_{ij}$ but are not included in $\beta x_{ij}$. Individual *i* chooses alternative *k* if and only if $U_{ik} > U_{ij}, \forall j \neq k$. Therefore, the probability that individual *i* chooses alternative *k* can be written as follows:

$$\begin{aligned} P_{ik} &= Pr(U_{ik} > U_{ij}, \forall j \neq k) \\ &= Pr(\beta x_{ik} + \varepsilon_{ik} > \beta x_{ij} + \varepsilon_{ij}, \forall j \neq k) \\ &= Pr\left(\varepsilon_{ij} - \varepsilon_{ik} < \beta x_{ik} - \beta x_{ij}, \forall j \neq k\right) \end{aligned} \quad (1)$$

Assuming that $\varepsilon_{ij}$ is distributed iid extreme value, the probability of choosing a given alternative (e. g., alternative 1 among three) is given by the multinomial logit model:

$$P_1 = \frac{exp(V_1)}{exp\,(V_1) + exp\,(V_2) + exp(V_3)} \quad (2)$$

In the context of our study, the multinomial logit model is the discrete choice model used to determine individual preferences for each of the three drinking water choices defined above.

*Hybrid choice model*

As mentioned earlier in the Introduction, the *perceived quality of water resources* is arguably not an exact measure of the way respondents perceive it and poses endogeneity issues. The *perceived price difference between tap water and bottled water* is prone to similar issues, which are handled by the use of a hybrid choice model.

Our modeling framework is hence the following: the perception of the price of bottled water as well as the perception of tap water quality are estimated in conjunction with the drinking water choice model. The different models are interacted by the means of two latent variables $\alpha_{quality}$ and $\alpha_{price}$ defined as follows, for each individual *i* (index *i* has been omitted for variables *x*):

$$\alpha_{quality,\ i} = \alpha_{quality,\ nitrates} \cdot x_{nitrates} + \alpha_{quality,\ rainfall} \cdot x_{rainfall} + \alpha_{quality,\ age} \cdot x_{age} + \alpha_{quality,\ gender} \cdot x_{gender} + \alpha_{quality,\ region} \cdot x_{region} + \alpha_{quality,\ income} \cdot x_{income} + \alpha_{quality,\ degree} \cdot x_{degree} + \sigma_{1,\ i}$$

$$\alpha_{price,\ i} = \alpha_{price,\ age} \cdot x_{age} + \alpha_{price,\ gender} \cdot x_{gender} + \alpha_{price,\ income} \cdot x_{income} + \alpha_{price,\ degree} \cdot x_{degree} + \sigma_{2,\ i} + chol \,.\, \sigma_{1,\ i}$$

The continuous variables are recoded so that they are now centered around 0. “Region” and “Degree” are binary variable vectors. $\sigma_1$ and $\sigma_2$ are random disturbances whose specifications are $\sigma_1 \sim N(0,1)$ and $\sigma_2 \sim N(0,1)$. *Chol* is an estimated parameter, which allows $\alpha_{quality,\ i}$ and $\alpha_{price,\ i}$ to be correlated by the means of a Cholesky decomposition. This has been done for identification purposes (see Davis (1993) and Reilly (1995) for more details about what is referred to as the *Two Measure Rule* of identification). The utility functions for the multinomial logit model are specified as follows for each individual *i* (index *i* has been omitted again for variables *x*):

$$V_{tap,\ i} = \beta_{tap,\ constant} + \beta_{tap,\ age} \cdot x_{age} + \beta_{tap,\ gender} \cdot x_{gender} + \beta_{tap,\ income} \cdot x_{income} + \beta_{tap,\ nb.children} \cdot x_{nb.children} + \beta_{tap,\ rural} \cdot x_{rural} + \theta_{tap} \cdot \alpha_{quality,\ i}$$

$$V_{filtered,\ i} = \beta_{filtered,\ constant} + \beta_{filtered,\ age} \cdot x_{age} + \beta_{filtered,\ gender} \cdot x_{gender} + \beta_{filtered,\ income} \cdot x_{income} + \beta_{filtered,\ nb.children} \cdot x_{nb.children} + \beta_{filtered,\ rural} \cdot x_{rural} + \theta_{filtered} \cdot \alpha_{quality,\ i}$$

$$V_{bottled,\ i} = \theta_{bottled} \cdot \alpha_{price,\ i}$$

The variables $\theta_{tap}$ and $\theta_{filtered}$ thus correspond to the effect of the latent variable $\alpha_{quality}$ on the probability of choosing tap water and filtered water with respect to tap water. The covariates entering the multinomial logit model are all related to the decision makers. None of the covariate entering the model are related to objective measures of the characteristics of each one of the three alternatives. As a result, it is necessary to normalize each variable to zero for one of the alternatives (including the constant given that only differences in utility matter as it is widely known). We choose to set $V_{bottled}$ as the base alternative. However, this does not mean that $V_{bottled}$ is set to be equal to zero for all the respondents as it is commonly found in similar multinomial logit models. Given the hybrid structure of our modeling framework, we can use the latent variable $\alpha_{price}$ to investigate the effect of differences in the perception of the price of bottled water with respect to tap water on the probability to mainly consume bottle water with respect to the other two alternatives.

The model is complemented by indicators of water quality perception and the perception of the price of bottled water relative to the price of tap water. Perception of water resource quality is an ordered categorical variable coded 0 (very poor), 1 (bad), 2 (good) and 3 (very good). We estimate this indicator *via* an ordered logit. That is (*n*=0, 1, 2, 3):

$$PI_{quality} = n = \left(\frac{1}{(1 + exp\left(\zeta_{quality} \cdot \alpha_{quality} - \tau_{quality_{n+1}}\right)}\right) - \left(\frac{1}{(1 + exp\left(\zeta_{quality} \cdot \alpha_{quality} - \tau_{quality_{n}}\right)}\right)$$

The coefficient $\zeta_{quality}$ thus corresponds to the effect of a variation in the latent variable on the perception of water quality. The parameters $\tau_{quality_n}$ are latent thresholds estimated by the model and normalized so that $\tau_{quality_0} = -\infty$ and $\tau_{quality\,4} = +\infty$. The indicator of the perception of the price of bottled water compare to tap water is constructed in a similar way: the price perception variable takes on the value 1 if the individual perceives correctly the price of bottled water compare to tap water (100x more expensive) and 0 if not. There comes a logit model:

$$PI_{price} = 1 - \left(\frac{1}{(1 + exp\left(\zeta_{price} \cdot \alpha_{price} - \tau_{price}\right)}\right)$$

The coefficient $\zeta_{price\,bottled\,water}$ thus corresponds to the effect of the latent variable $\alpha_{price}$ on the perception of the price of bottled water. $\tau_{price}$ is a constant. As mentioned above, the probability of drinking tap, bottled and filtered water is estimated in conjunction with the indicator related to the perception of tap water quality and the perception of the price of bottled water. The full model is estimated using the simulated maximum likelihood method, due to the presence of error terms $\sigma_1$ and $\sigma_2$. The log-likelihood is

$$LL(\Omega_U, \Omega_\alpha, \Omega_I) = \sum_{i=1}^{I} \quad ln \int_{\sigma_1} \quad \int_{\sigma_2} \quad P_i \,.\, PI_{quality,\ i} \,.\, PI_{price,\ i} g(\sigma_1) m(\sigma_2) d\sigma_1 d\sigma_2$$

**Results**

The model was estimated using 1000 Halton draws. The results are described in Table 7 (robust standard errors and T-ratios are reported).

**Table 7. Model results**

| | | | | |
|---|---|---|---|---|
| **Log-Likelihood (whole model)** | | | | -8277.281 |
| **Log-Likelihood (drinking water choice model)** | | | | -3591.931 |
| **Log-Likelihood (quality risk perception model)** | | | | -3054.118 |
| **Log-Likelihood (bottled water price model)** | | | | -1657.863 |
| **Adj. Rho square** | | | | 0.2527 |
| **AIC** | | | | 16652.56 |
| **BIC** | | | | 16954.51 |
| | **Estimate** | | **Rob. Std. Dev.** | **Rob. T-ratio** |
| | $\alpha_{quality}$ | | | |
| *Nitrates* | 0.0186 | *** | 0.0048 | 3.89 |
| *Rainfall* | -0.5567 | ** | 0.2674 | -2.08 |
| *Age* | -0.0397 | *** | 0.0078 | -5.1 |
| *Gender* | 0.8279 | *** | 0.2087 | 3.97 |
| *Region - Ile de France (reference category)* | | | | |
| *Region - Auvergne-Rhône-Alpes* | -0.6045 | *** | 0.182 | -3.32 |
| *Region - Bourgogne-Franche-Comté* | 0.0944 | | 0.2258 | 0.42 |
| *Region - Bretagne* | 0.1024 | | 0.2027 | 0.51 |
| *Region - Centre-Val de Loire* | 0.2456 | | 0.1979 | 1.24 |
| *Region - Grand Est* | 0.2037 | | 0.1542 | 1.32 |
| *Region - Hauts-de-France* | 0.9798 | *** | 0.1992 | 4.92 |
| *Region - Normandie* | 0.2269 | | 0.2154 | 1.05 |
| *Region - Nouvelle-Aquitaine* | -0.1394 | | 0.1576 | -0.88 |
| *Region - Occitanie* | -0.4945 | *** | 0.1507 | -3.28 |
| *Region - Pays de la Loire* | -0.5407 | *** | 0.1689 | -3.2 |
| *Region - Provence-Alpes-Côte d'Azur + Corse* | -0.0997 | | 0.1815 | -0.55 |
| *Income* | -0.1462 | ** | 0.065 | -2.25 |
| Education - No degree (reference category) | | | | |

| | | | | |
|---|---|---|---|---|
| *Education - Middle school degree* | 0.1308 | | 0.2272 | 0.58 |
| *Education - High school degree* | 0.3344 | *** | 0.1229 | 2.72 |
| *Education - Bachelor degree* | 0.2503 | ** | 0.124 | 2.02 |
| *Education - Master and higher degree* | 0.1674 | | 0.1076 | 1.56 |
| | **$\alpha_{price}$** | | | |
| *Age* | -0.0129 | *** | 0.0016 | -7.87 |
| *Gender* | 0.4254 | *** | 0.0564 | 7.54 |
| *Income* | -0.11 | *** | 0.0174 | -6.31 |
| *Education - No degree (reference category)* | | | | |
| *Education - Middle school degree* | 0.578 | *** | 0.2019 | 2.86 |
| *Education - High school degree* | 0.3374 | *** | 0.0858 | 3.93 |
| *Education - Bachelor degree* | 0.1563 | * | 0.0893 | 1.75 |
| *Education - Master and higher degree* | 0.0355 | | 0.0776 | 0.46 |
| $Chol$ | 0.0982 | | 0.0945 | 1.04 |
| | **$\beta_{tap\ water}$** | | | |
| *Constant* | 3.9628 | *** | 1.0952 | 3.62 |
| *Age* | -0.0629 | *** | 0.019 | -3.3 |
| *Gender* | 1.1791 | *** | 0.4269 | 2.76 |
| *Income* | -0.2952 | *** | 0.1116 | -2.65 |
| *Nb. Children* | 0.0787 | | 0.0606 | 1.3 |
| *Rural* | 0.3187 | ** | 0.1282 | 2.49 |
| $\theta_{tap\ water}$ | -1.3945 | *** | 0.3638 | -3.83 |
| | **$\beta_{filtered\ water}$** | | | |
| *Constant* | 0.7053 | | 0.4959 | 1.42 |
| *Age* | -0.0195 | *** | 0.0074 | -2.62 |
| *Gender* | 0.3114 | * | 0.1753 | 1.78 |
| *Income* | -0.0676 | | 0.0459 | -1.47 |
| *Nb. Children* | 0.1574 | *** | 0.055 | 2.86 |
| *Rural* | 0.2705 | ** | 0.1145 | 2.36 |
| $\theta_{filtered\ water}$ | -0.4238 | *** | 0.1573 | -2.69 |
| | **$\beta_{bottled\ water}$** | | | |
| $\theta_{price}$ | 0.2198 | ** | 0.1005 | 2.19 |
| | ***Indicator - Quality*** | | | |
| $\zeta_{quality}$ | -0.4078 | *** | 0.0616 | -6.62 |
| $\tau_{quality_1}$ | -3.9401 | *** | 0.1334 | -29.53 |
| $\tau_{quality_2}$ | -0.9302 | *** | 0.0774 | -12.02 |
| $\tau_{quality_3}$ | 3.1032 | *** | 0.1094 | 28.37 |
| | ***Indicator - Price of bottled water*** | | | |
| $\zeta_{price}$ | -5.1074 | *** | 1.3482 | -3.79 |
| $\tau_{price}$ | 2.8938 | *** | 0.7789 | 3.72 |

*Note :* $p$-values * $p < 0.10$ ; ** $p < 0.05$ ; *** $p < 0.01$.

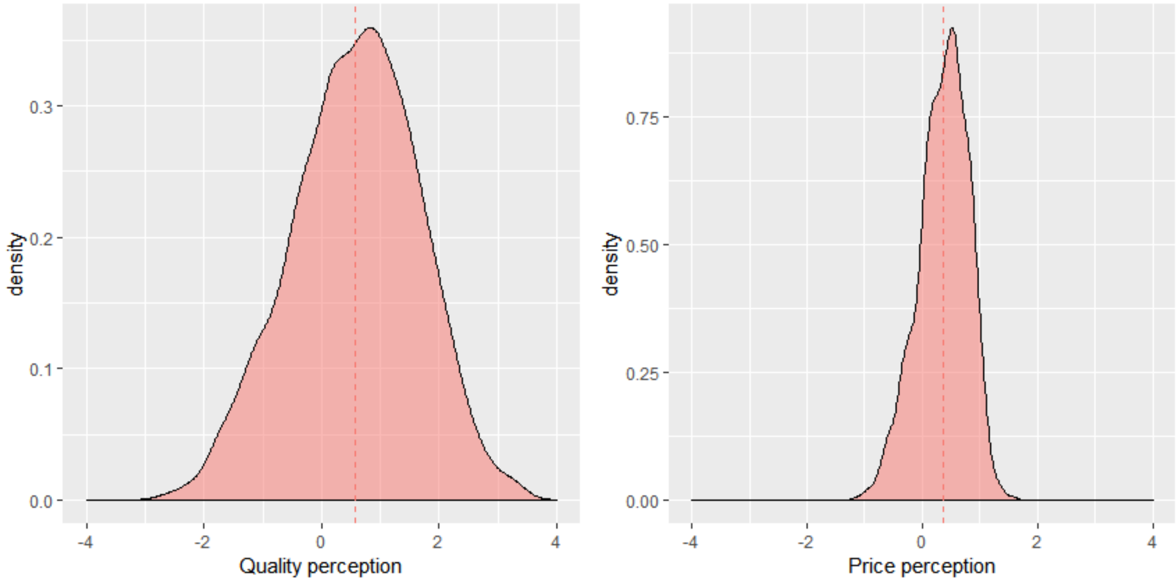
The results should be interpreted as follows: an increase in the latent variable $\alpha_{quality}$ decreases the probability of drinking tap water compared to bottled water as $\theta_{tap\,water}$ is negative (-1.3945) and significant at the level of 1%. An increase in this same latent variable also decreases, to a lesser extent, the probability of consuming filtered water because the variable $\theta_{filtered}$ is also negative (-0.4238) and also significant at the 1% level. Finally, an increase in the latent variable $\alpha_{quality}$ decreases the probability of stating a better perception of water quality. Indeed, the variable $\zeta_{quality}$ is found to be significant and equal to -0.4078. This indicates that respondents who are less likely to state that the quality of the tap water is good are also less likely to drink it, in line with expectations. We also find that an increase in the latent variable related to the perception of the price of bottled water, $\alpha_{price}$, decreases the probability of having a correct perception of this price given that $\zeta_{price}$ is equal to -5.1074. At the same time, an increase of $\alpha_{price}$ increases the probability of drinking bottled water since the estimated value of $\theta_{price}$ is found to be 0.2198. In other words, respondents who are less likely to know the correct price of bottled water with respect to tap water are also more likely to consume it (remember that actually, half the population underestimates bottled water price compared to tap water price, as stated earlier). This important (and strongly significant) result has not been observed elsewhere in the received literature to the best of our knowledge.

The distribution of the two latent variables across the sample population is described in Table 8 and Figure 1 below. As expected, given the underlying assumption of our model, the two latent variables are nearly normally distributed and centered on zero.

**Table 8. Descriptive statistics of the expected values for the latent variables in the sample**

| Latent variable | Mean | SD | Min | Max |
|---|---|---|---|---|
| Quality perception | 0.572 | 1.076 | -2.849 | 3.672 |
| Price perception | 0.364 | 0.434 | -1.156 | 1.592 |

**Figure 1. Distribution of the expected values for the latent variables in the sample**




We now look in details at the factors influencing the level of each of the two latent variables. The latent variable $\alpha_{quality}$ is strongly influenced by the nitrate level and rainfall levels measured around the respondents' homes. Indeed, the level of the latent variable increases as the nitrate level increases (the coefficient is found to be equal to 0.0186 and significant at the 1% level), indicating a *robust link between actual and perceived quality*. As said earlier, nitrate pollution from agriculture is common knowledge, which is reflected in the latter result. We also find that the latent variable decreases with increasing rainfall levels (-0.5567), which suggests that the observation of high levels of rainfalls results in favorable individual opinion on the quality of surface water or groundwater. $\alpha_{quality}$ is lower for older individuals (-0.0397) and higher for women (0.8279). The latent variable also varies by region and level of education. The latent variable $\alpha_{price}$ decreases with age (-0.0129) and is found to be higher for women (0.4254), which means that women are less likely to know the actual price of bottled price with respect to tap water. This is a surprising result but it is in line with what is found in the data. Indeed, only 27.71% of male respondents and 14.37% of female respondents stated that the price of bottled water is about 100 times higher than the price of tap water. This difference between genders is significant at the 1% level according to a $\chi^2$ test ($\chi^2$ (1) = 94.1904, *p-value* = 0.000). Moreover, $\alpha_{price}$ decreases when income increases. We also find that different education levels have different effects on the value of the latent variable.

Finally, we analyze the results of the consumption choice model. Older individuals are less likely to drink tap water and filtered water compared to bottled water. In addition, women are less likely to drink bottled water, all other things being equal (the net effect of gender is different, however, as women are less likely to perceive the quality of the tap water as "good" in comparison to men). In order to clarify the effect of some of the most relevant variables on drinking water choice, we provide the following market shares derived from the model results:

**Table 9. Market shares**

| | Tap water | Bottled water | Filtered tap water |
|---|---|---|---|
| Female | 40.80% | 39.05% | 20.15% |
| Male | 40.10% | 38.07% | 21.83% |
| Rainfalls below average | 37.90% | 40.67% | 21.43% |
| Rainfalls above average | 44.52% | 35.24% | 20.24% |
| Nitrates below average | 45.48% | 34.44% | 20.08% |
| Nitrates above average | 34.57% | 43.41% | 22.02% |
| Rural | 42.08% | 35.15% | 22.77% |
| Non-Rural | 39.98% | 39.58% | 20.44% |
| Income below average | 41.02% | 38.90% | 20.08% |
| Income above average | 39.33% | 37.89% | 22.77% |

It is clear from Table 9 that the overall effect of gender on drinking water choice is not very important in comparison to the effect of pollution (Nitrates) and rainfalls. We also observe some important discrepancies between rural and non-rural regions. Surprisingly, respondents who reported a higher income level are less likely to drink bottled water, which confirms the idea that this is a good for which consumers are relatively price insensitive and highlights the importance of modeling consumption choices based on the perception of the price rather than the price itself.

## Conclusion

In this paper we propose to use a hybrid choice model to assess the role of perception variables in drinking water choices, which has not previously be done in the received literature. In doing so, we address two main problem posed by the use of perception variables in empirical works on pro-environmental and/or averting behaviors: measurement error and endogeneity. We believe that such an approach will continue to prove useful not only in the field of water economics, but more generally in environmental economics.

From an empirical point of view, we show that the perception of nitrate pollution from agriculture encourages bottled water consumption. This individual perception of water resources quality is significantly associated with the objective water resources quality, which undoubtedly reflects a good level of information of the population on nitrate pollution from agriculture. Also, our econometric strategy makes it possible to show that individuals who are less likely to report the correct price difference between tap water and bottled water are less likely to consume tap water. Taken together, our results suggests that individuals do form perceptions, perhaps even beliefs, about tap water based on the information they have at their disposal, but that these perceptions may be far from objective reality. From a policy recommendation perspective, this suggests to better inform people about how drinking water is actually produced and priced.

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# Appendix: The hybrid choice model adapted from Ben-Akiva et al., 2002)