Willingness to Pay for Drinking Water in the Sahara: the Case of Douentza in Mali

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Consentement à payer pour de l'eau potable au Sahara : le cas de Douentza au Mali

Résumé – La présente étude compare deux méthodes de prévision du consentement à payer pour de l'eau potable dans des systèmes d'adduction en région semi-urbaine au Sahara. Les deux modèles sont estimés en fonction des caractéristiques hypothétiques de divers points d'adduction possibles. Le premier modèle, reposant sur une régression multiple, prévoit la somme d'argent qu'un ménage consentira à payer pour chaque seau d'eau potable provenant d'une source donnée. Le second modèle, employant une spécification de type logit, vise à expliquer la décision d'acheter ou non de l'eau potable. Les deux approches reposent sur le modèle de prix complets tel que proposé par la théorie de la demande. Ce modèle explique la quantité d'eau demandée en fonction des prix et du coût d'opportunité du temps affecté à la consommation. Dans nos modèles empiriques, la variable explicative qui s'avère la plus significative est la proximité de la nouvelle source prévue divisée par la distance à la meilleure source existante.

Mots-clés:
eau potable, consentement à payer, enchères, Mali

Willingness to pay for drinking water in the Sahara : the case of Douentza in Mali

Summary – *This study compares two methods of predicting the willingness to pay for drinking-water delivery systems in the semi-urban Sahara as a function of the hypothetical characteristics of possible water delivery points. The first, a linear regression model, predicts the monetary amount a household should be willing to pay for each bucket of water from the source. The second, a LOGIT model, explains the decision to purchase water or not. Both methods are based on the full-price budget constrained model of standard demand theory — which explains quantity demanded as a function of prices and the opportunity cost of time spent on consumption. The most consistently significant explanatory variable in our empirical models is the relative distance to the planned new source compared to the best existing source.*

Key-words:
drinking water, willingness to pay, auctions, Mali

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PROVIDING potable water at an affordable price is the first concern of drinking water system planners. Given today's emphasis on responsible fiscal planning, structural adjustment, and the disengagement of the government in all but essential sectors, it is vital to be able to predict with a high level of accuracy the financial and economic viability of proposed drinking water projects. Nowhere in less developed countries (LDCs hereafter) is this concern more urgent or dramatic than in the Sahelian region of West Africa, where massive structural adjustment is under way and encroaching desertification makes water an increasingly precious commodity.

Within this context, the economic condition of Mali is particularly precarious. The weighted average GNP per capita, which was $270 around the time of the study, decreased to $223 in 2000[1]. Mali's per capita income is barely 50 % of the average for sub-Saharan Africa[2]. Similarly, under 5 mortality (218 per 1000), and life expectancy at birth (42 years) in 2000 are all worse than average for sub-Saharan Africa and for LDCs in general. The problem of water quality is inextricably related to these last two indicators of social well-being. According to a study conducted in Mali by the DNHE (1993), the use of water in two representative villages averages 5.25 litres per person/day for consumption, 3.7 for cooking, 3.25 for dishwashing and 6.45 for toilet use for an average household of 5.3 residents, including 1.2 wives per male household head. These water needs had to be met with a daily food budget averaging 300 CFA francs[3] per day and dipping to less that 200 francs for the 39 % poorest households.

Douentza, the site of the present study, is one of Mali's major semi-urban centers[4]. During the 1983-84 drought, many families fled to Douentza in search of greater food security. Seasonally cut off from the Niger River, Douentza's surface water is highly polluted because it is

[1] This statistic was obtained from the web site of *The Economist Intelligence Unit* whose address is: *http://store.eiu.com/index.asp?layout=show_sample&product_id=50000205&country_id=ML*.

[2] *Source:* World Bank's web site: *http://www.worldbank.org/data/databytopic/ ssa-wdi.pdf*.

[3] The CFA franc is a currency used by several French-speaking countries in Africa. Until December 2001, it was pegged to the French franc (100 CFA francs/1 French franc). It is now pegged to the Euro.

[4] Douentza is located in the far Eastern part of Mali. It is the commerical hub for three overlapping geographical zones, notably Mopti. Partly because of its economic location, the population of Douentza and its surroundings, estimated at 56000 at the time of the study and 65 000 today, has grown at 3.9% per year.

used to make bricks, water livestock, irrigate vegetable plots, wash children and do laundry. To make matters worst, it is also infested with Guinea worms. As a result, the local population relies on one manual pump, five collective wide-diameter wells, and 21 private wells, which draw clean water from a rocky substrate of an average depth of 6.5 meters. Unfortunately, water from wells lying in the center of the city is bitter because nitrates seep in from neighboring latrines.

For these reasons, a drinking water delivery system based upon public fountains and taps was installed by the Canadian International Development Agency in 1982. The older half of the city already has access to the delivery system while the other newer half does not. Even in the older half, residents complain about two problems. Firstly, the management committee has neither specialized training nor extensive contact with the local population. Secondly, after the original generator broke down, a replacement was obtained on loan from a highway construction project, but in exchange for half of the drinking water produced by the project. Despite these constraints, the system supplies 1 567 cubic meters of water per month for domestic consumption in the older half of Douentza, with a seasonal variablility of only 21 %. Users are generally satisfied with the quality of the service. The existing source is judged to be reliable and to give clear, healthy and tasty water. The distance from the household to the source was less than a third of that to the nearest well (149 *vs* 474 meters). Furthermore, water prices were as low as in any other urban area in Mali: 15 litres cost 6.25 CFA francs at the tap, or 10 CFA if delivered to the household by a socially disadvantaged woman[5].

The purpose of this study is to assess the financial and economic feasibility of extending the drinking water delivery system to the newer half of the city, which does not yet have an alternative to existing wells. In this sense, the study should be of interest in consultative procedures which link eventual users of potable water delivery systems to the engineers responsible for planning them. We propose and test methods for predicting the adoption rate of a public drinking water delivery fountain in semi-urban regions. Specifically, we rely on observed choices made in the older half of the city of Douentza (where a fountain exists) to predict which factors are most likely to influence the behavior of the residents of the newer half. We implement a hypothetical auction game to predict the monetary willingness to pay for potable water from a public fountain that has yet to be built. Taken together, the results from these two approaches can be used to calculate the numerator of the benefit: cost ratio necessary for judging project feasibility.

[5] A socially disadvantaged woman is one who is either a widow, or is married to an unproductive or unrespected man, or has little access to land (often as a result of the first two reasons), or has no children to take care of her in her old age.

THE CONCEPTUAL FRAMEWORK

Microeconomic theory provides necessary elements to model the decision process of a household's choice of water supply site. We define U as the utility function of a representative household which consumes water in a given use, U_c as the sub-utility function for all other goods aggregated into a composite good, U_i as the sub-utility function for water used for purpose $i = 1, \ldots, N$ (*e.g.* drinking, cooking, laundry…), q_{ij} as the quantity of water consumed for purpose i from water-source $j = 1, \ldots, S$ and Q_j as the quantity of water supplied at water-source j, aggregated over purposes.

The water consumption decision problem for the household can be expressed as follows[6]:

$$Max\ U = U\left(U_1(q_{11} + \ldots + q_{1S}), \ldots, U_N(q_{N1} + \ldots + q_{NS}), U_c\,(Q_c)\right) \quad (1)$$

subject to: $\sum_{i=1}^{N} q_{ij} = Q_j$, the total quantity of water from source j; $\sum_{j=1}^{S} P_j Q_j + P_c Q_c \leq \omega T_\omega + \mu$, the budget constraint, with ω defined as the wage rate, T_ω as the time spent working and μ as non-wage income; $\sum_{j=1}^{S} \tau_j Q_j + \tau_c Q_c + T_\omega \leq T$, the total time constraint, with T the amount of time available. As is well known, the last two constraints combine to form the so-called full price budget constraint:

$$\sum_{j=1}^{S} (p_j + \omega\tau_j)\, Q_j + (p_c + \omega\tau_c)\, Q_c \leq \omega T + \mu \quad (2)$$

The full price includes the price of the water from water-source j, but it also includes the opportunity cost of time to walk to water-source j. As one would expect from a glance at the first order conditions, corner solutions are likely in such a model (*i.e.*, $\frac{\partial U_i}{\partial q_{ij}} - \lambda\,(p_j + \omega\tau_j) < 0 \Leftrightarrow q_{ij} = 0$ where λ is defined as the marginal utility of income). For water used for a specific purpose, the perfect substitutability across water-sources implies that consumers choose the source with the lowest full price. This simple, yet insightful, model could be extended to account for a positive externality like a "conversation service" associated with the exchange of information between users of a given water source and with the possiblity of briefly shedding otherwise imposed social roles[7]. This could be introduced in our model by relaxing the additivity assumption for the sub-utility functions. Such an extension would help explain why:

[6] The sub-utility fonctions need not all contain the same number of water sources as the water from some sources need not be suitable for certain uses.

[7] This is particularly true in the case of women in traditional societies who frequently prefer wells lying far from the eyes and ears of men.

– members of a household may cover variable distances between 200 and 500 meters to obtain equal quantities of water (White *et al.*, 1972),

and why,

– when the level of service passes from a neighborhood tap to a tap in a private yard, there is a dramatic increase in water consumption.

These observations do not refute the pertinence of the model in its simplest form. They merely indicate that other factors must be added to full prices and income to enrich the specification of our theoretical and empirical models, provided of course that the described behavior is fairly common and not simply a low-occurrence oddity. Anthropological and sociological notions provide potential insights. Traditional cultures, notably in rural Africa, weight monetary capital, power, knowledge, health, family, moral values and God in ascending order while cultures of the European homelands of economic theory tend to rank them in descending order (Guéneau, 1986). Hence, prices and physical effort may not be the sole (perhaps the primary) determinants of water demand. It is possible that a household gets most of its water from a close source and the rest of its water needs plus a "conversation externality" from a more distant water-source. From an econometric perspective, the selection of a water source simultaneously involves a discrete choice of the source and a continuous choice of the quantity to consume. Because the quantity of water demanded often determines the choice of delivery point (Whittington *et al.*, 1987), econometric analyses must attempt to deal with such simultaneity.

Because it is difficult to integrate in a model all potential factors (*e.g.*, quality, technical feasibilty, economic efficiency and social relations with other users) affecting water demand in rural Africa (White *et al.*, 1972), Morel de l'Hussier (1990) recommends direct estimation of the utility function by appealing to discrete choice analysis/random utility theory. A representative household chooses water used for purpose i from source j instead of from source k if $U_{ij} > U_{ik}$ and $U_{ij} > 0$. Then, the 0-1 choice indicator Y_j takes a value of 1. Random utility theory decomposes utility into a deterministic component ψ and a random component ε such that: $U_{ij} \equiv \psi_{ij} + \varepsilon_{ij}$. In a probabilistic sense, this implies:

$$P(Y_{ij} = 1) = P(\psi_{ij} + \varepsilon_{ij} > \psi_{ik} + \varepsilon_{ik}), \quad \forall k = 1, \ldots, j-1, j+1, \ldots, S \qquad (3)$$

The above expression clearly demonstrates that the choice model and the distribution of the random utility depend upon the distribution of the random error terms. Several examples from the literature (*e.g.* Mercier and Lent (1990) for farm computers in the US, and Malla (1983) for rice seed in Nepal) apply the Gumbel distribution. For the specific case of drinking water systems, Whittington *et al.* (1987) and Mu *et al.* (1990) condition the deterministic part of their choice model on some characteristics of the water points, as perceived by households, household income and demographic and social characteristics of the households. The cumulative distribution of discrete choices across users indicates the percentage of a population using a water point. It is commonly estimated by a logistic function. To predict an individual household's choice, one must estimate its threshold of acceptance.

Welfare economics helps measure this threshold in terms of the monetary value of utility. Specifically, the willingness to pay (WTP) is the sum of real expenditures at market prices plus the value of consumer surplus above market prices that the household would have been willing to pay. As a measure of Hicksian compensation, the WTP has been used especially in benefit/cost analyses of government projects and the evaluation of retribution in legal litigations. Two distinct reference situations may be used: the compensating variation and the equivalent variation[8]. Numerous studies show that the willingness to receive (WTR) is not only one to three times or more the WTP (Coursey *et al.*, 1987), it is also much more difficult to estimate (Carson and Navarro, 1988). Despite the advantages of WTP, Briscoe and de Ferrenti (1988) blame its non-use in planning drinking water projects on the lack of an empirically validated method of estimating WTP.

Of the three methods cited in Whittington *et al.* (1988a) to measure WTP, neither the hedonic pricing (of water characteristics) nor the variable parameters approach seems adapted to the analysis of Saharan water demand. Because contingent valuation measures the WTP for a service offered on a "contingent" (hypothetical, non-existing) market, it seems more suitable for the problem at hand. Indirect contingent evaluation, based on consumer theory, measures the value of WTP from existing behavior in terms of quantities consumed and the specific expenditures (cost, time, effort) in the present. As such, it is subject to problems of missing data and structural changes of unknown magnitudes[9].

Direct contingent evaluation asks participants to predict their own behavior under a hypothetical situation described by the researcher. Of the various possible techniques, Whittington recommends the use of a questionnaire which simulates the market negotiation between suppliers and customers. The resulting auction game includes yes-no questions and a sequence of prices established beforehand. In addition to the common biases due to the non-neutrality of the interviewer or the questionnaire, some respondents might underestimate the importance of the study (hypothetical bias), or misunderstand the advantages of the new system (information basis), or they might say that they will accept any price in

[8] Let $M(p^0, U^0)$ be the expenditure function evaluated at the current prices and utility level, $V(p^0, E)$ be the indirect utility function evaluated at current prices and expenditure level E, and p^1 be a higher price, then the compensating variation is defined as $CV = M(p^1, V(p^0, E)) - M(p^0, V(p^0, E))$ while the equivalent variation is defined as $EV = M(p^1, V(p^1, E)) - M(p^0, V(p^1, E))$.

[9] Young (1996) also provides a good overview of methods. Unfortunately, his review is more oriented toward studies in which water is an intermediate good in agricultural production or else a recreational good.

hope of free riding (strategic bias). However, it is possible to control such WTP biases[10]. Given that the notions of choice of water-source and WTP are closely related, they are used interchangeably henceforth.

As hinted before, the choice of a water source can be conditioned by many variables. For example, with respect to the purchasing power of the household in Chili, an increase of 10 % in household income increases water consumption by 4 % (Briscoe and de Ferranti, 1988). In Zimbabwe, women are willing to pay 40 % more for access to public taps than their husbands in order to free themselves for more fulfilling and remunerative handicraft or small commercial activities. In terms of the social characteristics of the household, while the number of women of all ages increases the likelihood of using a more distant or less reliable source, a high dependency ratio (aged, infirm, student or infant members of the household to fully active members) reduces the likelihood of using an inconvenient source. As to the perceptions of the users, the higher the level of education of women, the greater the demand for clear water. Similarly, female literacy, and the perception of benefits were found to be significant in Asthana's (1997) study conducted in India. Gender and educational level also emerged as important factors in Jayasundara *et al.*'s (1999) study conducted in Sri Lanka. Evans (1992) found that the degree of participation by traditional authorities and the local population, the degree of community cohesion, and the level of decision-making and financial responsibility of the populace all increase the willingness to pay for a source. The demand for competing services (notably a private latrine on one's property in areas where the water table cannot support both a latrine and a private tap) may lead the household to choose a public water source.

As to the characteristics of the water source, Jayasundara *et al.* (1999) identified the type of water source, perception of water quality and reliability as key factors conditioning WTP. Physical effort to get the water obviously matters, but it is not necessarily just a linear function of distance since the depth of the well and the topography might have to be taken into account. Some households are too poor to purchase a rope long enough to reach the water table of an open well. In this case, women lend the rope among themselves in exchange for services (such as filling the buckets of the owner of the rope). Briscoe and de Ferranti found that the price elasticity of demand for water was – 0.3 for Chili. The value of the WTP for a private hook-up is 2.3 times higher than that for a public fountain or tap, which in turn is 2-4 times higher than for a hand pump (Briscoe, 1987). The quality of the water (taste, odor, appearance, firewood necessary to bring it to the boiling point) all complicate the choice of water source and the willingness to pay. For example, on holidays and marriage days, the hand pump is preferred to the

[10] A study conducted in Haiti suffered from none of the aforementioned biases (Whittington *et al.*, 1988b).

dirtier deep-well. And the quality of service (as reflected by the percentage of time the system is broken down) can have a major influence on the choice of site (Wiseman, 1987; Katko, 1990).

The theory of Kornai (1982) on waiting lines in shortage economies also explains why women may prefer to frequent a more distant pump where the probability of a long wait is lower. Because women only have access to information and to free social exchanges when they are far away from men, a distant source with a high full price may actually be quite appealing! By the same token, people with conflictual relationships or of different ethnic groups might choose less convenient water sources to avoid each other.

Based upon Douentza's specific water-supply problem and our review of the literature, we wish to ascertain whether theoretically motivated variables, like wealth/income and distance, and other potential factors like socio-demographic variables significantly influence WTP and the decision to purchase or not water from various delivery points. The next section describes the models used to achieve these objectives.

THE EMPIRICAL IMPLEMENTATION OF THE CONCEPTUAL FRAMEWORK

Evaluation methods differ according to the degree of contingency (*i.e.* the level of uncertainty surrounding the quality of a service or a good). A high level of contingency implies that the residents are unfamiliar with the proposed technology and have great difficulty in imagining and evaluating its true value. In contrast, increasing levels of certainty are associated with having seen a water delivery system elsewhere, being currently served by a dysfunctional system and being currently served by a functional system.

In this context, four approaches may be used to predict the adoption rate. **Approach 1** is characterized by the reliance on a similar/reference locality where the inhabitants currently benefit from a potable water delivery project. A linear regression model serves to estimate the parameters necessary to predict the WTP auction values in a new locality for which a potable water delivery project is in the planning stage. If the WTP is superior to the reference price in the existing site, the adoption choice is predicted to be positive[11]. **Approach 2** is based on a small sam-

[11] Because not everyone is buying water, one might be tempted to deal with the selection bias problem with a Tobit or double-hurdle type of estimator. However, because *"heteroskedasticity will usually be present in practical applications, there is no general guarantee that the attempt to deal with censoring by replacing OLS with the Tobit maximum likelihood estimator will give estimates that reduce the (selection) bias"* (Deaton, 1997, p.88).

ple of residents in the new locality scheduled for a project. One administers not only the auction game, but also an extensive socio-economic questionnaire. Although the level of contingency is necessarily higher in this case, it is often possible to generate statistically acceptable regression coefficients. A larger-scale survey to quantify only the key explanatory variables is then conducted in the same locality. The results serve to estimate the WTP, which is then compared with the reference price. **Approach 3** models choice based on a sample from a reference locality. The dependent variable is the observed behavior (1 = use, 0 = non-use) of residents. When the model is transposed to a target locality and fitted to the same regression coefficients, it serves to estimate the probability of adoption of an individual household. The number of households for which the estimated probability of adoption exceeds 0.5 serves to predict the adoption rate for the locality as a whole. **Approach 4** models choice with a large sample from the new locality. The result of the contingent evaluation for the WTP constitutes the numerator of an index of acceptabilty; the denominator is the planned selling price. The value of the index determines choice as $Y^* = 1$ only if the index is greater than or equal to 1, otherwise, $Y^* = 0$. When aggregated, the model estimates the probability of adoption.

All four of these methods contribute useful insights and mutually complementary information and ideally, water planners would have access to results from all four. In the present study, however, questions of political sensitivity and the desire to avoid creating possibly false hopes in the residents of the newer part of the city limited the research to the older part. This study therefore used only approaches 1 and 3 plus the auction game element of approach 2. We rely on the OLS estimator to assess the significance of factors that could potentially influence WTP. The willingness to pay for drinking and cooking water from water-source j, WTP_j, is a continuous variable measured in units of local currency, the CFA franc, per bucket of water. The explanatory variables considered in choosing an adequate model specification include an index of wealth constructed from the presence of luxury/status goods in the household[12], daily household food expenditures, a dummy variable for occupational status, the number of rooms or monthly rent of the dwelling, the value of remittances from migrant members of the household, household size, number of children, the dependency ratio, a dummy variable for education attainment, a dummy variable for tenure insecurity, a dummy variable for ethnicity, indicators of household perceptions of the quality of a proposed or alternative water source constructed from binary evaluations of convenience and reliability, as well as the perceived quality of the water (taste, odor, appearrance and cleanliness) and the relative

[12] Examples of such goods include high quality construction materials, cola nut, cigarettes, tea, bicycle, cart, motor-bike. In a study conducted in Burkina Faso at about the same time, Calkins *et al.* (1996) validated a Guttman scale for the accumulation of such goods. The number of goods was highly correlated with the overall income of the household.

distance of the well relative to the tap. A logit regression is used to assess the significance of factors that could potentially influence the probability that the household would elect to purchase water from a given source. The factors considered are the same as for the WTP regression. The choice of these factors was motivated by extensive field observations and our review of the literature. We relied on the usual criteria to guide our search for optimal model specifications (*i.e.* theoretical priors, residual based tests, signs and magnitude of the coefficients…).

These variables, as well as the observed water use choices were collected using a detailed survey questionnaire in 62 households in the older part of the city of Douentza. WTP was collected with an auction game for the 62 households. After explaining the contingency scenario, the interviewer asked the respondent how much the household would be willing to pay for the existing service[13], given hypothetical improvements in reliability and management. The distances between households and the various water sources are directly observable. Furthermore, the person interviewed can perceive both the level of service (proximity to the tap relative to an alternative source) and the advantages of clean water. Hence, the contingency element of the question is limited to conjectures about the non-fraudulent management of funds, the competent management of a depreciation fund and the reliability and convenience (*i.e.* the availability at desired hours of the day) of the system.

The question is structured by statements corresponding to various levels of auction price, that is: "To buy water from the tap, would you accept to pay 5 CFA francs for 1 bucket? 15 for 2 buckets? 10 for 1 bucket?". The starting price and the sequence of auction prices are determined in advance for each of the three rounds of the auction game. The three rounds have different starting prices. For a given round, the measure of WTP is the midpoint between the auction price accepted and the auction price refused. Thus, for a person accepting to pay 5 CFA, but refusing 15 CFA for 2 buckets, we assumed that the household would be willing to pay 6.25 CFA per bucket. The measure of WTP is the average reservation price over three rounds.

THE RESULTS

Of the sixty-two household heads interviewed, we found that 40 % held paying jobs, a mere 23 % had completed at least 6 years of primary education and 77 % were men. Women had a much lower level of education than men and none of them had a salaried job in the formal sec-

[13] The type of service is the public tap managed by a water guard who receives a fixed amont in CFA francs for each bucket.

tor of the economy. In our sample, 74 % of households bought their drinking and cooking water at fountains, and 26 % used wells. The relative distance to the alternative source was the most important distinguishing factor between the two groups.

Table 1.
Distribution of bids and summary statistics by bidding round

WP interval (CFA francs)	**Observed frequency (%)**	**Cumulative frequency (%)**	
From 0 to 5	6.50	6.50	
From 5.1 to 10	39.40	75.80	
From 10.1 to 15	19.30	95.10	
From 15.1 to 20	4.80	100.00	
Initial bid	**10 CFA francs for 1 bucket**	**15 CFA francs for 2 buckets**	**5 CFA francs for 1 bucket**
Frequency	37.00	36.00	37.00
Mesures of central tendency			
Average WTP	7.88	7.88	7.77
Modal WTP	6.25	6.25	6.25
Measures of dispersion			
Variance	15.90	12.70	14.10
Std. deviation	3.98	3.56	3.76
Coefficient of variation	0.51	0.45	0.48
WTP and household characteristics			
	Uneducated	**Educated**	
Mean (std.deviation)	7.8 (3.5)	8.9 (6.2)	
	Male-headed	**Female-headed**	
Mean (std.deviation)	8.1 (3.5)	7.1 (4.2)	
	Non-ethnic	**Ethnic**	
Mean (std.deviation)	7.6 (3.4)	11.9 (6.0)	

N = 62 observations

The distribution of the auction results reported in Table 1 has a mean WTP value of 7.85 CFA which is 26 % higher than the current price at the fountain. The coefficient of variation is 48 %, a sure sign of a good deal of dispersion in bids. Indeed, the highest bid was 20 CFA. A chi-square test showed that the distribution of responses was not statistically different from a normal distribution. Tests of significant differences in the responses between auction games with different beginning prices were implemented (*i.e.* 10 CFA for 1 bucket, 15 CFA for 2 buckets and 5 CFA for 1 bucket). The null hypothesis of insignificant differences could not be rejected. Hence, we concluded that the WTP estimates were robust across auctions and that respondents supplied non-random WTP estimates. The bottom part of Table 1 displays WTP estimates for different groups of households. The difference in WTP between male-headed households and female-headed households was found to be statistically significant. This outcome can potentially be explained by the greater purchasing power of men. The rather large standard deviations attest to the variability in WTP within socio-demographic groupings. From the rather small (large) variability between (-within) groups, we can conjecture that socio-demographic variables may not have significant effects when regressed on WTP.

WTP estimates reported in the literature vary tremendously and hence it is difficult to ascertain whether the ones reported above are reasonable. A population's evaluation of the adequacy of its current water supply may vary tremendously from one country to another and sometime, as is the case here, between different parts of a same city. Therefore, the dispersion in WTP estimates should not be surprising. Recent studies about methodological issues also provide some explanations as to why the range of WTP estimates is wide. In several studies criticized by Reddy (1999), a rule of thumb of 5 % of total expenditures is arbitrarily assumed to be the maximum a household is willing and able to pay. Hardner's (1996) WTP estimates measured in terms of labor, for an isolated community in northwest Ecuador, was as high as 23 % of real income. However, other studies contend that such estimates could be too high. From empirical research conducted in Nigeria, Whittington *et al.* (1992) found that either giving respondents a day to think before formulating a WTP estimate or allowing them to revise their initial bid resulted in significantly lower WTP estimates for improved water systems. This conclusion was robust since it held for both public taps (72 % of respondents) and private connections (61 %). Along the same lines, Davis and Whittington (1998) found that the additional information derived from public meetings greatly tones down the initial overvaluation characterizing the estimates provided by survey respondents[14]. In a recent study in Mexico, Galindo and Montesillo (1999) found the demand for water to be very inelastic to movements in relative prices and income.

Given that our WTP estimates were robust to changes in auction starting prices and that they seemed reasonable, we proceeded with the identification of factors that affect the levels of WTP. The coefficients and the corresponding p-values for the factors conditioning WTP are reported in Table 2. The adjusted R^2 of the regression is low, but this seems common in WTP studies relying on the OLS estimator and cross-section data[15]. Still, theoretically-motivated variables are significant and their coefficients have the expected signs.

[14] In their study, 80 % of households had indicated that they would use a system of public taps during a household survey. However, only 50 % said so in a community meeting.

[15] Whittington *et al.* (1988b) report an unadjusted R^2 of 0.25 for their WTP regression on Haitian data.

Table 2.
WTP and choice regressions

Estimation technique **Dependent variable**	OLS WTP	LOGIT CHOICE
	Coefficient **(*p*-value)**	**Coefficient** **(*p*-value)**
Constant	3.650 (0.33)	-0.256 (0.00)
Purchasing power indicators		
Index of wealth	0.244 (0.02)	n.a.
Daily food purchases	n.a.	0.008 (0.06)
Occupational status	-1.507 (0.12)	n.a.
Social characteristics		
Household size	0.263 (0.04)	n.a.
Number of children	n.a.	0.700 (0.02)
Tenure insecurity	2.228 (0.05)	n.a.
Water source characteristics		
Relative distance	0.266 (0.03)	1.120 (0.00)
Adjusted R^2	0.14	n.a.
Maddala R^2	n.a.	0.42

n.a.: not applicable; N = 62 observations

Regarding household characteristics, it comes as no surprise that wealth, a continuous variable approximated by the sum of the binary possession/non-possession of several luxury goods, is positively related to WTP. Thus, purchasing power, as proxied by wealth, is a significant determinant of WTP. Similarly, the coefficient for household size is positive and significantly so, indicating that the feeling of urgency of meeting water needs embodied in WTP increases with the number of people in the household. Insecurity of land tenure discourages the construction of one's own well and as such it tends to raise the WTP for a public water-source. This first effect is reinforced by a second one according to which free lodgers, all other things being equal, have more discretionary income to spend on water. Occupational status, with a *p*-value of 0.12, does not significantly determine WTP at commonly used levels of significance (*i.e.* 1 %-10 %). We considered introducing education as a conditioning factor, but it was consistently insignificant in explaining WTP when we conducted specification searches. It is possible that an historical event, such as an epidemic of Guinea worm, sufficiently marked the collective memory as a lesson of the importance of modern water sources that formal education is no longer a determinant of demand for public taps in Mali. Alternatively, the non-significance of education could possibly be attributed to its correlation with wealth. This is supported by the fact that the *t* statistic of wealth fell whenever education entered the specification of the model. This sort of outcome is indicative of multicollinearity. It is on that basis that education was excluded from our final WTP model specification.

Table 3. **Impact on WTP of bringing taps closer to households**

Distance to well (meters)	Distance to tap (meters)	Relative tap density*	Increase in density (%)	Increase WTP (%)	WTP (Francs CFA)
474	149.00	3.18	0.0	0.000	7.80
474	119.20	3.98	25.0	0.067	8.32
474	99.33	4.77	50.0	0.133	8.84
474	85.14	5.57	75.0	0.200	9.36
474	74.50	6.36	100.0	0.266	9.87
474	72.33	6.55	106.0	0.282	10.00
474	66.22	7.16	125.0	0.333	10.39
474	59.60	7.95	150.0	0.399	10.91
474	54.18	8.75	175.0	0.466	11.43
474	50.00	9.48	198.0	0.527	11.91
474	49.67	9.54	200.00	0.532	11.95

* Relative tap density is defined as the ratio of distance to well over distance to tap.

As predicted by our simple full price theoretical model, the index of proximity of the tap relative to the well turned out to be highly significant. The positive sign indicates that WTP increases as the relative proximity of the tap increases. This result is particularly important for engineers working on water projects. For example, a 50 % increase in the relative distance of water sources increases WTP by 13.3 % when the initial ratio relative distance-WTP is equal to one. Of course, lower relative distance-WTP ratios depress the elasticity. Table 3 shows that increasing the density of the water delivery network (defined as the ratio of meters to the well over meters to the tap) from the current 3.18 to 4.77 would allow Douentza water planners to charge 8.84 instead of 7.80 CFA. Alternatively, the taps or fountains would have to be arranged at a density of at most 6.55, such that no household would lie further than 72 meters from a tap, for water to be priced at 10 CFA or more. Whether such density levels are feasible or not is not obvious. Our results are still germane because we have demonstrated that relative distance separating the household from two alternative sources clearly matters when explaining WTP for drinking water.

The logit regression presented in Table 2 helps to clarify the motivation behind the adoption of the fountain by 74 % of the households in our sample. The results indicate that increasing the relative proximity of the fountain by 10 % raises the probability of adoption by 5.8 %. At a relative distance of 2, it is 2.88 times more likely that a resident will use the service than not. Increasing the relative distance from 2 to 4 raises the odds ratio to 27[16].

Unlike for the WTP regression, the number of young children was found to be significant in the logit regression explaining the probability of adoption. The presence of individuals under 5 years of age increases the likelihood of buying water from the water-guard because of the time and energy necessary to breast-feed and care for young children and heightened concerns about water quality. Increasing the number of children by one from the mean increases the probability of purchase from 74 % to 85 %. By contrast, the dummy variable for overall household education (1 if at least one member of the household has had formal education, 0 otherwise) was never significant throughout our specification searches and it was removed from the final specification. Purchasing power, as proxied by daily food expenditures, turned out to be significant at a level of significance of 6 %, which is slightly higher than the usual 5 %. Nevertheless, we feel at ease in concluding that purchasing power has a positive effect on the probability of adoption. Overall, the results for WTP and the probability of adoption are quite consistent with one another. Furthermore, they confirm that factors identified by our simple theoretical model, namely purchasing power and distance, indeed play an important role in explaining the demand for water.

CONCLUSIONS

We implemented auction games to obtain estimates of willingness to pay (WTP) for drinking-water delivery systems. Then, we employed regression techniques to identify and quantify the impact of factors conditioning WTP and the probability of adoption of a given water-source. The robustness of WTP estimates to changes in the starting price used in

[16] In the logit model, the log of the odds ratio is: $\ln\left(\frac{\Pr(y=1)}{\Pr(y=0)}\right) = X'\hat{\beta}$, where X is a matrix of explanatory variables and $\hat{\beta}$ is a vector of regression coefficients. It follows that the elasticity of the odds ratio relative to a given explanatory variable is given by: $\left(\partial\ln\left(\frac{\Pr(y=1)}{\Pr(y=0)}\right)/\partial x_k\right) * x_k = \hat{\beta}_k x_k$. Furthermore, the probability of purchase and the elasticities of that probability with respect to explanatory variables can be computed from:

$\Pr(y=1) = \frac{1}{1+e^{(-X'\hat{\beta})}}$ and $\frac{\partial \Pr(y=1)}{\partial x_k} * \frac{x_k}{\Pr(y=1)} = \frac{\hat{\beta}_k x_k e^{(-X'\hat{\beta})}}{\left(1+e^{(-X'\hat{\beta})}\right)}$. Typically, elasticities are not evaluated at every observation, but at the mean values of the explanatory variables or else at specific values corresponding to a given profile of respondents.

the auction game led us to to conclude that the auction game is a valid method for estimating the value that an individual household assigns to a proposed new distribution service for a good. Generally, we found no evidence of bias imputable to the structure of the auction game[17]. Hence, this approach could be extended to other public or private goods, such as electricity, education and health insurance.

The results for Douentza confirm that the relative distance separating the household from two alternative sources contributes significantly to explaining both WTP and water site choice. Proxies for purchasing power were also found to be significant. Hence, our results support the prediction from the simple microeconomic model of water demand developed at the outset. However, our empirical investigation identified household size and tenure insecurity as key factors influencing WTP estimates for Douentza residents. We also found that the number of children influenced the probability of adoption of a water-source.

Despite the appeal of modeling the valuation of the extension of an existing water system in one half of a locality to the other half based upon the behavior of the people who already have access to the water, caution must be exercised when attempting to generalize our results to other sites. First of all, omitted conditioning factors, like the depth of the water table, topography or the overall availability of water, which vary little from one household to another within a village, may be very different in other villages. Ideally, one would deal with this issue by estimating site-specific models or by introducing additional variables in regressions on the pooled data set. Eventually meta-analyses, along the lines of Heady and Hexem (1978), could be implemented. Secondly, even though auctions are attractive mechanisms to obtain WTP estimates, their implementation is challenging and perhaps more so in a LDC context[18]. In our experiments, 54 % of the respondents in each of the three auction scenarios cited the well-known current price of water (6.25 CFA/bucket) as their willingness to pay. It could be that the current price was indeed the maximum that some of the participants were willing to pay, but it is likely that some participants had a poor understanding of the WTP concept[19]. Indeed, the use of the word "willingness" in a society newly introduced to civil and political rights seems

[17] For example, no one observed buying water from the fountain refused to pay the same price during the game.

[18] It is difficult even for educated populations in North America (Cho, 1996) to determine how much they would be willing to pay for intangible benefits of improved water systems, such as lower microbial levels, sweeter taste and collective ecological improvement.

[19] Even though much time is devoted to insure that the participants fully understand what is asked of them, WTP studies are often confronted to odd responses on the part of some participants. For example, Hardner (1996) reports that 28 % of his respondents supplied bids of zero.

to be somewhat problematic. Also, there might have been some confusion as to whether the proposed water system would provide for daily needs or for emergencies and occasional difficult periods. Furthermore, some of the respondents did not seem to understand that a relatively low reserve price meant that it would not be possible for the household to benefit from the proposed service.

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