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Determinants of Domestic Water Use by Rural Households Without Access to Private Improved Water Sources in Benin: A Seemingly Unrelated Tobit Approach

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Abstract This paper analyzes the determinants of domestic water use in rural areas. The focus is on households without access to private improved water sources. These households use either only free sources, only purchased sources or a combination of free and purchased sources. We also analyze households' water use behaviors as a function of water availability by explicitly estimating domestic water use for both rainy and dry seasons. Using a Seemingly Unrelated Tobit approach to simultaneously account for the censored nature of water demand and the correlation of error terms between free and purchased water use equations, we find that purchased water demand is perfectly price inelastic due to water scarcity. The important determinants of water use are household size and composition, access to water sources, wealth and time required for fetching water. Nevertheless, the effects of these determinants vary between household types and seasons, and the policy implications of the findings are discussed.

Keywords Domestic water management · Rural households · Seemingly unrelated tobit · Benin

1 Introduction

Water is an essential component of life, and its availability and quality are crucial. Although domestic water consumption accounts for only 7% of the total water use in Africa (Hinrichsen et al. 1997), the benefits related to an improved water supply, such as effects on health, time savings and high productivity, are quite immense (HDR 2006; Sharma et al. 1996). For a household to fully benefit from an improved water supply, it must have indoor access to safe and reliable water sources. While this is almost always found in developed countries, such access is far from a reality

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in developing countries, especially in rural areas. Genuine concerns have been raised about inadequate access to improved water sources. The expansion of access to safe and reliable water sources, especially in Africa and Asia, is therefore one of the "Millennium Development Goals". In Benin, access to an improved water supply remains a major concern. Despite Benin's good level of per capita water availability (FAO 2003), only 23% of the population has drinking water within their residence (INSAE 2003).[1] Likewise, recent estimates have indicated that only 54% of the rural population and 76% of the urban population have access to improved drinking water sources (WHO and UNICEF 2006; INSAE 2003). Therefore, an efficient water management policy is important if the health and welfare of the population, particularly in rural areas, are to be improved.

Efficient management of water resources for rural areas requires a full understanding of existing patterns of water demand (Nyong and Kanaroglou 1999). Demand analysis[2] is an important tool for the economic analysis of household behavior with regard to water use. Demand analysis can help to determine factors influencing water demand, predict their effects and help to develop policy options accordingly. With a view toward contributing to such knowledge, this study aims to analyze factors affecting the domestic water use of rural households without access to piped water within their residences. These households use different water sources: namely, free water sources, purchased water sources or a combination of both free and purchased water sources. These sources may be public improved sources or private traditional sources. We are also interested in investigating household domestic water use as a function of water availability by explicitly estimating water use for the rainy and dry seasons, when water is, respectively, in surplus and scarce.

Methodologically, household water demand is derived from the household decision making process. For rural households relying only on public or traditional sources, a non-separable household model is needed because households allocate their labor between income generation activities and water fetching. Such analysis, using the Seemingly Unrelated Regression (SUR) method, was conducted by Acharya and Barbier (2002) for rural households that only collect water, only purchase water from vendors or both purchase and collect water. In the present study, we identify three types of households: namely, those that use only free water sources, those that use only purchased water sources and those that use both free and purchased water sources. Based on this categorization, this paper makes three main contributions to the existing empirical work. First, we use a Seemingly Unrelated Tobit (SURT) approach to address the censored nature of water demand, which the method applied by Acharya and Barbier (2002) fails to account for. In addition, the SURT approach can appropriately account for the correlation between the disturbances of two equations (Zellner 1962). Second, we recognize that, in rural developing countries, not only does the quantity of water use vary between the dry

[1]The quantity of water available is 3,954 m^3 per capita per year, ranking Benin in the 99th position out of 180 countries (FAO 2003). With this value, Benin is classified amongst "economic water scarcity" countries, for which problems with the water supply are due to either financial or management capacity.

[2]Even though we are aware of the difference between demand and consumption, for simplicity, "water demand" in this paper refers to consumption or use. Therefore, we use the terms "water demand", "consumption" and "use" interchangeably.

and rainy seasons, but seasonal variation in the determinants of household water use also exists. Although other studies of Benin and elsewhere have found that the water use quantity is not the same in the rainy season as in the dry season (Keshavarzi et al. 2006; Hadjer et al. 2005), these studies have not clearly separated factors that affect household behavior in each season. However, apart from water availability, other factors can also cause water use to vary between seasons. For instance, the opportunity cost of time required for fetching water is much larger in the rainy season than in the dry season. Furthermore, a clear distinction of factors affecting water use in each season is important because it may reveal which factors are more important for water management under different conditions of water availability. Third, this paper focuses on households without access to private improved water sources. Little is reported about water demand for these households in the literature. Indeed, most work on water demand in developing countries has focused on households with access to a piped network (Zekri and Dinar 2003). Other work has attempted to identify determinants of households' decisions to connect to a piped network (Persson 2002; Madanat and Humplick 1993). Moreover, recent studies on water use in Benin have combined urban and rural populations and targeted neither rural households nor households that lack access to private improved sources (Hadjer et al. 2005).

The remainder of this paper starts with a presentation of the modeling approach in Section 2, followed by a brief description of the study area and data used for model estimation in Section 3. Section 4 presents and discusses the results of the determinants of water demand in the rainy and dry seasons as well as seasonal variations in household behavior. Finally, Section 5 concludes with a summary of the findings and policy implications.

2 Modeling Approach

The Seemingly Unrelated Regression (SUR) model is well known in the econometric literature (Greene 2000; Zellner 1962), and it has recently been applied in many disciplines, including economics (Smale et al. 2003; Acharya and Barbier 2002). The advantage of the linear SUR method is that its estimators are more efficient than those obtained by unrelated least squares methods if the error terms of two equations are correlated. However, it has been shown that linear SUR estimators are biased and inconsistent in large samples for limited dependent variables (Greene 1981). Therefore, nonlinear versions of the SUR model, such as the Seemingly Unrelated Tobit (SURT)[3] approach, would be appropriate if the dependent variables are censored. Although both the SUR and SURT models are capable of handling correlation between errors of estimating equations, the advantage of using the SURT over the SUR method is the ability to accommodate for censored dependent variables. In this paper, the dependent variables are non-negative and left-censored because a number of households did not use either water from free sources or water from purchased sources. For instance, households that use only free water sources

[3]The nonlinearity of the SURT model arises from the censored nature of the dependent variables, while the parametric formulation of the model is still linear in the parameters.

have a zero value for the quantity of purchased water.[4] Similarly, households that rely only on purchased water sources have a zero value for the quantity of water obtained from free sources. Consequently, several values of the dependent variables are zero in both the free and purchased water equations. Thus, in order to have a valid model specification, we would have to account for the censored nature of the dependent variables. For this reason, we use the Seemingly Unrelated Tobit (SURT) approach in the present study rather than the SUR model.

To introduce the SURT model, for a sample of observations $t = 1,\ldots,n$, we consider Y_{1t}^* and Y_{2t}^* as two latent continuous variables defined by:

$$\begin{cases} Y_{1t}^* = \beta_1 X_{1t} + \varepsilon_{1t} \\ Y_{2t}^* = \beta_2 X_{2t} + \varepsilon_{2t} \end{cases}. \tag{1}$$

Let Y_{1t} and Y_{2t} represent, respectively, the daily quantities of free and purchased water used by a household. We assume that all households have access to at least one free and one purchased water source.[5] Y_{1t} and Y_{2t} are non-negative, and we assume that Y_{1t} and Y_{2t} are both left-censored at zero, i.e., a considerable number of households report zero consumption of free or purchased water. Additionally, we assume a linear functional form for water demand. The observed data Y_{1t} and Y_{2t} are related to the latent variables defined in Eq. 1, and the demand functions for free and purchased water are specified as follows:

$$\begin{cases} Y_{1t} = Y_{1t}^* = \beta_1 X_{1t} + \varepsilon_{1t} \text{ if } Y_{1t}^* > 0 \text{ and } Y_{1t} = 0 \text{ otherwise} \\ Y_{2t} = Y_{2t}^* = \beta_2 X_{2t} + \varepsilon_{2t} \text{ if } Y_{2t}^* > 0 \text{ and } Y_{2t} = 0 \text{ otherwise} \end{cases}, \tag{2}$$

where X_{1t} and X_{2t} are vectors of independent variables, β_1 and β_2 are vectors of unknown coefficients, ε_{1t} and ε_{2t} are the error terms, assumed to be distributed according to $N(0, \Omega)$, and Ω is the variance-covariance matrix (VCM) presented as follows:

$$\Omega = \begin{bmatrix} \sigma_1^2 & \rho_{12} \\ \rho_{12} & \sigma_2^2 \end{bmatrix}. \tag{3}$$

If one assumes that the covariance between ε_{1t} and ε_{2t} is equal to zero (i.e., the off-diagonal elements in Ω are zero), then both demand equations in Eq. 2 can be estimated separately using the unrelated Tobit regressions. In this study, however, some households use a combination of free and purchased water. These households are included in both the free and purchased water demand equations, so the disturbance terms across these two equations may be correlated. In addition, it is economically reasonable to assume that, for households using both free and purchased water sources, the decision of the amount of water from free sources to be used is related to the decision of purchased water consumption. In this case, the correlation between ε_{1t} and ε_{2t} would be significantly different from zero. Therefore,

[4] For brevity reasons, we use the terms "purchased water" for water obtained from purchased sources and "free water" for water from free water sources.

[5] In the study area, it is quite reasonable to assume that all households have access to at least one free and one purchased water source, but factors such as distance will determine the quantity of water use from each source.

a SURT model that estimates water demand equations for free and purchased sources jointly would be better than estimating the two equations separately. The advantage of SURT for estimating the two demand equations in system 2 is the ability to handle both the censored nature of the data and the correlation between error terms across the two demand equations.

The unknown parameters (β coefficients in system 2 and elements of the VCM in Eq. 3) can be consistently estimated using the maximum likelihood technique. Since we have two dependent variables, there are four possible combinations of observations at their censoring points. Therefore, the likelihood function for Y_{1t} and Y_{2t} is (Yen and Lin 2002):[6]

$$
\begin{aligned}
L_{1,2} = & \prod_{Y_{1t}=0, Y_{2t}=0} \Psi\left(-X_{1t}\beta_1/\sigma_1, -X_{2t}\beta_2/\sigma_2, \rho_{12}\right) \\
& \times \prod_{Y_{1t}=0,\ Y_{2t}>0} \sigma_2^{-1}\phi\left[\left(Y_{2t}-X_{2t}\beta_2\right)/\sigma_2\right]\Phi\left[\frac{-X_{1t}\beta_1/\sigma_1-\rho_{12}\left(Y_{2t}-X_{2t}\beta_2\right)/\sigma_2}{\left(1-\rho_{12}^2\right)^{1/2}}\right] \\
& \times \prod_{Y_{1t}>0,\ Y_{2t}=0} \sigma_1^{-1}\phi\left[\left(Y_{1t}-X_{1t}\beta_1\right)/\sigma_1\right]\Phi\left[\frac{-X_{2t}\beta_2/\sigma_2-\rho_{12}\left(Y_{1t}-X_{1t}\beta_1\right)/\sigma_1}{\left(1-\rho_{12}^2\right)^{1/2}}\right] \\
& \times \prod_{Y_{1t}>0,\ Y_{2t}>0} \sigma_1^{-1}\sigma_2^{-1}\ \psi\left[\left(Y_{1t}-X_{1t}\beta_1\right)/\sigma_1,\ \left(Y_{2t}-X_{2t}\beta_2\right)/\sigma_2,\ \rho_{12}\right],
\end{aligned}
$$

where $\phi(\cdot)$ is the univariate standard normal probability density function (pdf); $\Phi(\cdot)$ is the univariate standard normal cumulative distribution function (cdf); and $\psi(\cdot,\cdot,\cdot)$ and $\Psi(\cdot,\cdot,\cdot)$ are the bivariate standard normal pdf and cdf, respectively.

Following Greene (2000), the average marginal effect (ME) across all individuals in the censored regression model is:

$$
\mathrm{ME} = \frac{1}{n}\sum_{t=1}^{n}\frac{\partial E\left[Y_{it}\,|X_{it}\right]}{\partial X_{it}} = \frac{1}{n}\sum_{t=1}^{n}\beta\ \Phi\left(\frac{\beta X_{it}}{\sigma_i}\right). \tag{4}
$$

The average marginal effects provide additional insight into the factors affecting household water use. We calculate the average marginal effects for all independent variables included in our empirical model. Based on microeconomic theory and the literature on water demand in rural areas of developing countries, the choice and justification of the independent variables used in this paper to estimate the system of demand equations (Eq. 2) can be summarized as follows:

Water price Demand theory states that, as the price of a good increases, the demand for that good will, ceteris paribus, decrease (e.g., Zekri and Dinar 2003; Froukh 2001). Therefore, it is expected that price will negatively influence the quantity of water use from purchased sources.

Time for fetching water There is an opportunity cost of time used for fetching water and an effort required to carry heavy water buckets. This implies that the farther

[6] Another way to specify the likelihood function of the SURT can be found in Huang et al. (1987).

away a source is located from the house and the longer one must queue, the less water from that source will be used (Gazzinelli et al. 1998; Sandiford et al. 1990). Thus, it is hypothesized that the time for fetching water (walking time plus waiting time) will be negatively related to the quantity of water use. The time for fetching water is included in both the free and purchased water equations since, in most cases, water sources are not located within the residence.

Education It is expected that, as the level of education increases among household members, the level of household awareness about the health benefits of water use (quantity and quality) also increases (Keshavarzi et al. 2006; Sandiford et al. 1990). It is thus hypothesized that education level will positively affect the level of water use. As a proxy for education level, we use the number of adults who have completed primary education in the household. This variable accounts for not only the education level of the household's head, but also those of other household members, including the wives.

Wealth The literature has shown a positive relation between wealth and water use (Sandiford et al. 1990). It is assumed that poverty negatively affects water use because poor people cook less and often have less clothing to wash. In this study, household asset expenditure is used as a proxy for wealth. In fact, the economic development literature supports the notion that, when dealing with household surveys in developing countries, household expenditure is a better proxy for household welfare than income (Deaton 1997).

Household size and composition Domestic water consumption will likely increase with household size. Following Keshavarzi et al. (2006) and Froukh (2001), both household size and composition affect water use, and moreover, household size has been found to be the most important factor affecting water consumption. In our analysis, household size, the ratio of children to adults and gender of the household head are considered.

Occupation of household head It has been shown that the household head's occupation significantly determines the amount of domestic water use, but the magnitude of the impact depends on the type of activities (Acharya and Barbier 2002). It is hypothesized that farming households will use less water than non-farm households.

Village population In an area where people rely mainly on public water sources (either free or purchased), it is expected that per capita water use will decrease as the population increases. Furthermore, people in the study area can only collect a fixed quantity of water in order to allow everybody to have at least a small quantity of water. In a large population, a household member may have to queue several times before obtaining the desired quantity. Therefore, we hypothesize a negative relationship between population size and water use. Such a hypothesis has been used in a similar context by Babel et al. (2007).

Water accessibility It is expected that, as with other economic goods, better accessibility will positively affect the quantity of water consumption. Access to different water sources, namely, public wells, public pumps and private wells, is included in our regression models. This variable has been used in other studies (Sandiford et al. 1990).

In the empirical model, correlation between the independent variables has to be checked to avoid the problem of multicollinearity. In this paper, partial correlation coefficients between independent variables are used to check for possible multicollinearity problems. In addition, all independent variables of the SURT model have to be exogenous. Therefore, to avoid inconsistency of the SURT estimates, we compute the Durbin–Wu–Hausman test via instrumental variables (IV) techniques to detect a possible endogeneity problem.

3 Data, Water Use Practices and Summary Statistics

The study area includes the central and northern parts of the Oueme river basin of Benin Republic (Fig. 1). Similar to the country overall, 60% of the population in the study zone lives in rural areas, and the population density is 44 inhabitants per km^2 in this zone (INSAE 2003). This area is about 44,000 km^2 in size and includes, fully or partly, 23 of the country's 77 districts. The geology of the study area is dominated by the crystalline soil with solid rock masses (Igue 2005). The hydrogeology in the area is based on fractured rock formations with minimal matrix porosity such that groundwater is derived primarily from regions of alteration or fractures (Engalenc 1978). In Benin, water supply within the crystalline rocks is commonly developed from three ranges of depth that are differentiated by available porosity (Silliman et al. 2007): (1) Superficial aquifers in the shallow (altered rock) are commonly exploited as water supply based on hand-dug wells; (2) Deep fractured rock, with

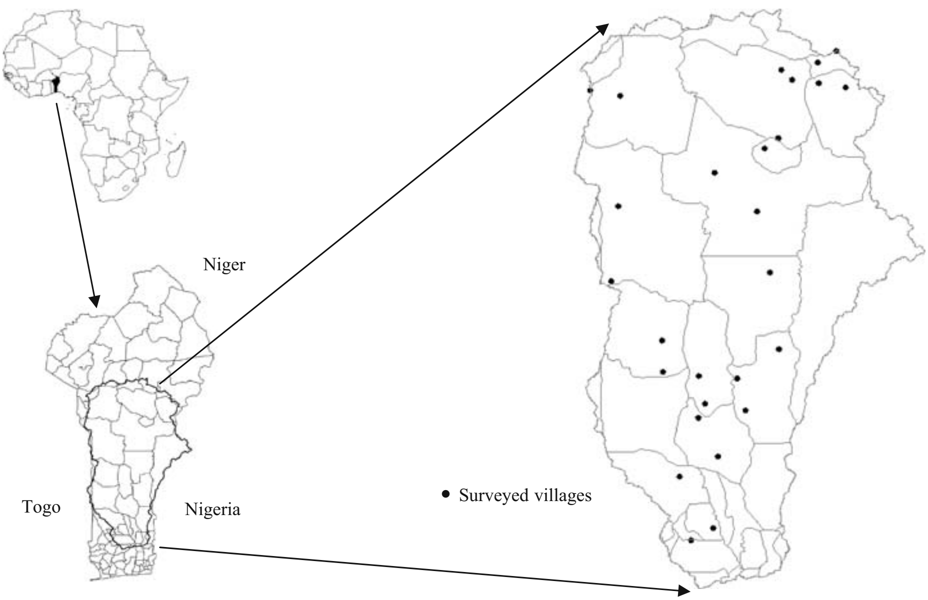

Fig. 1 Location map of the study area (Oueme river basin in Benin) and surveyed villages

groundwater flow reliant solely on the porosity of the fractures. Development is pursued through drilling to a median depth of 60 m. These wells are commonly equipped either with submersible pumps or with manual pumps (hand or foot pumps) especially in the rural areas; and (3) Fracture zones at the transition between the superficial aquifers and the deep aquifers have been exploited mainly through drilling.

Hand-dug wells penetrated only into the superficial aquifers and were generally private. Because of hydrogeology and financial constraints, digging private wells (hand-dug wells) that can reach deep aquifers is difficult and expensive in many parts of the study area. In addition, because of the low infiltration and the fact that rainwater is mainly drained toward the southern part of the country, the problem of water accessibility is enormous in the study zone compared to the whole country.

The survey was carried out between April and August 2007, and a two-stage stratified random sampling technique based on location and water accessibility was used. In the first stage, surveyed villages (Fig. 1) were selected according to their location (district) and water accessibility. This selection strategy was employed in order to include, for each district, villages with different levels of water accessibility. In each district, villages were classified into two groups: villages with high levels of water accessibility (fewer than 250 persons per public pump) and villages with low levels of water accessibility (more than 250 persons per public pump).[7] One village was randomly selected per group. In total, 27 villages were selected. A group discussion with the rural population on water issues was organized in each village using a qualitative data collection guide. During this step, a draft of the structured questionnaire was pre-tested with some households. Additionally, for the purpose of a sampling exercise and due to the lack of a recent census, an exhaustive list of household heads was established in each village. Based on this list, a random selection of 12 households per village was made in the second stage. In total, 325 households were surveyed. The primary data collected include mainly general household characteristics, daily water use in rainy and dry seasons, water sources, water constraints, time required for fetching water and water price. Using these data, we estimated the system of demand equations (Eq. 2) for the rainy and dry seasons separately.

The average daily domestic water consumption per household, as derived from our sample, is 251.8 l in the rainy season and 215.9 l in the dry season (i.e., about 29 and 25 l per capita in the rainy and dry seasons, respectively). Although these water consumption estimates were obtained by an interview-based survey, other studies based on observational data have found similar results (Hadjer et al. 2005).[8] A comparison of means reveals that water use during the rainy season is significantly greater than during the dry season ($t = 17.18$, significant at the 1% level). Furthermore, considering water use by the different types of households according to the seasons, we found that, in the rainy season, daily water consumption is 269.52 l for households that combine free and purchased water, 241.61 l for households that

[7]This categorization is based on WHO (2005) which recommended at least one water point per 250 people for an adequate water supply.

[8]Hadjer et al. (2005) observed that the mean daily water consumption in four villages and one small town in northwestern Benin was 244 l per household.

Table 1 Daily water consumption for different types of households (in liters day^{-1} $household^{-1}$)

Household type	Rainy season			Dry season		
	Obs.	Free water	Purchased water	Obs.	Free water	Purchased water
Households using free and purchased water	201	163.90	105.62	109	134.12	120.34
Households using free water	92	241.61	0	41	201.82	0
Households using purchased water	32	0	169.77	175	0	195.18
All households	325	169.76	82.04	325	70.44	145.46

Own household survey, 2007

use only free water and 169.77 l for households that use only purchased water sources (Table 1). In the dry season, water consumption falls to 254.46 l for households that use both free and purchased water and to 201.82 l for households that use only free water, but it increases marginally to 195.18 l among households that only use purchased water. This is attributable to the fact that some households change from using both free and purchased water in the rainy season to using only purchased water in the dry season. Indeed, 66% of users of only purchased sources in the dry season combined free and purchased sources in the rainy season.

Table 2 presents descriptive statistics of water use practices and those of the independent variables. In the study area, rural households have no access to piped water within their residences. They rely on either public improved sources or private traditional sources. The public improved sources include public wells (non-mechanized wells), public pumps (human-powered hand or foot pumps) and public taps. While the public pumps and taps are based on drilled wells that penetrated into the deep aquifers, the public wells penetrated generally only into the medium aquifers. Water is hauled from the public wells using a skin bag or other form of container (such as a plastic bucket) tied to the end of a hand-line. Private traditional sources are hand-dug wells that may belong to the households or to their neighbors. The average water price from improved sources is 7.24 CFA per 25 l[9] (0.011 euro per 25 l). Prices are seen to vary slightly between water sources and villages. In 30% of villages (28% of surveyed households), the water price is ten CFA per 25 l (0.015 euro) at public pumps and five CFA per 25 l (0.008 euro) at public wells. Only 4% of households pay 15 CFA per 25 l (0.023 euro) for public tap water. Water from the household's own private and neighboring wells is generally free, but public wells and pumps are also free water sources in some villages. Although all surveyed households had access to at least one free and one purchased water source (depending on the distance), 68%, 52% and 41% had access to a public well, a public pump and surface water (river or lake), respectively (Table 2). Only 30% of households had access to private wells (their own and neighboring).

With the exception of personal private wells, water from other sources needs to be hauled by household members, who must also queue at the water sources.

[9]The ISO currency symbol of CFA is XOF. Average exchange rate in 2007: 1 US$ = 478.634 CFA and 1 €= 655.957 CFA. Water is mainly collected using local buckets that contain about 25 l of water. The average price per bucket is 0.011 (or 0.44 euro per cubic meter).

Table 2 Descriptive statistics of explanatory variables

Variable	Definition (unit)	Mean	Standard deviation
Household size	Household size	8.56	4.31
Expenditure	Household asset expenditure (in 1,000 CFA[a])	282.65	537.82
Population	Village population in 2007 (units of 1,000 inhabitants)	2.59	1.45
Gender	Household head sex (1 for female and 0 for male)	0.09	0.28
Ratio of children to adults	Ratio of children to adults	0.94	0.71
Occupation	Household head occupation (1 if household head has agriculture as main occupation, 0 otherwise)	0.73	0.45
Education	Number of adults who have completed primary education	2.09	1.95
Price	Water price (CFA per 25 l)	7.24	3.79
Walk time in dry season	One way walking time to water source in dry season (minutes)	10.84	14.47
Queue time in dry season	Daily waiting time at water source in dry season (minutes)	312.62	257.78
Time for fetching water in dry season	Daily total time (walking and waiting) for fetching water in dry season (minutes)	323.46	258.00
Walk time in rainy season	One way walking time to water source in rainy season (minutes)	7.64	8.84
Queue time in rainy season	Daily waiting time at water source in rainy season (minutes)	57.48	79.78
Time for fetching water in rainy season	Daily total time (walking and waiting) for fetching water in rainy season (minutes)	65.12	82.75
Access to public pump	Access to public pump (1 if yes and 0 otherwise)	0.52	0.50
Access to public well	Access to public well (1 if yes and 0 otherwise)	0.68	0.47
Access to own opened well	Access to own private opened well (1 if yes and 0 otherwise)	0.09	0.29
Access to other opened well	Access to neighboring private opened well (1 if yes and 0 otherwise)	0.14	0.35
Access to river or lake	Access to river or lake (1 if yes and 0 otherwise)	0.41	0.49
Observations		325	

Own results

[a] Average exchange rate in 2007: 1 US$ = 478.634 CFA

This imposes time and effort costs on households. Depending on the distance, the average one-way hauling time is not significantly different between seasons (11 and 8 min in the dry and rainy seasons, respectively). Although the hauling time is short, the majority of time spent for fetching water is the waiting time. After arriving at the water source, household members have to queue for almost one hour per day in the rainy season. In the dry season, the waiting time is much longer: on average five times longer than during the rainy season (Table 2).

4 Results

4.1 Model Performance

The Seemingly Unrelated Tobit (SURT) estimation results for the system of water demand (Eq. 2) are presented in Tables 3 and 4 for the rainy and dry seasons, respectively. The correlation coefficient (ρ) between the error terms was estimated to be −0.42 for the rainy season and −0.48 for the dry season. These values are significantly different from zero based on asymptotic t-tests. This reveals a possible gain of efficiency in the SURT estimation *vis-à-vis* an unrelated Tobit approach. This empirical result confirms our hypothesis that, for the group of households that combine free and purchased water, the decision of water quantity collected from free sources is related to the decision of water quantity obtained from purchased sources. Furthermore, the models are globally significant at the 1% critical level as shown by the χ^2 test. This result shows that the SURT model is appropriate for both the censored nature of water demand from different sources and the correlation between error terms across the two water demand equations (free and purchased). In addition, none of the partial coefficients between covariates were high or significant for all

Table 3 Seemingly Unrelated Tobit (SURT) model results for free and purchased water demand (in liters day^{-1} household^{-1}) in the rainy season

Variable	Free water demand			Purchased water demand		
	Coef.	t-test	Marg. effects	Coef.	t-test	Marg. effects
Household size	25.54***	6.30	24.43	5.24**	2.06	4.74
Household size squared	−0.45***	−2.75	−0.43	0.05	0.41	0.05
Gender	−5.55	−0.34	−5.31	−17.88	−1.38	−17.21
Ratio of children to adults	−7.06	−0.90	−6.75	−8.94*	−1.83	−8.60
Expenditure	0.04***	4.38	0.04	−0.03 E-02	−0.41	−0.00
Population	−2.59	−0.71	−2.47	−1.57	−0.64	−1.51
Occupation	−43.62***	−4.26	−41.73	−31.61***	−4.15	−30.43
Education	−0.40***	−2.81	−0.39	0.05	0.02	0.05
Time for fetching water in rainy season	−0.17**	−2.50	−0.17	−0.22***	−4.71	−0.21
Access to public well	32.75***	3.02	31.33	−20.04***	−2.58	−19.29
Access to public pump	−21.97**	−2.24	−21.02	17.96*	1.76	17.47
Access to own opened well	43.29***	2.67	41.42	–		
Access to other opened well	31.40***	2.89	30.10	–		
Price	–			−1.70	−1.37	−1.65
Constant	23.98	1.17	–	88.94***	5.42	–
Variance σ_1^2 [a]	53.29***	22.67				
Variance σ_2^2 [a]	77.50***	24.50				
Corr. coef. ρ_{12} [a]	−0.42***	−3.46				
χ^2 (df = 12)	153.15***					
Log-likelihood	−2952.82					
Observations	325					

Own results

$^*p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$

[a]These are the elements of the variance–covariance matrix Ω (Eq. 3)

Table 4 Seemingly Unrelated Tobit (SURT) model results for free and purchased water demand (in liters day^{-1} household^{-1}) in the dry season

Variable	Free water demand			Purchased water demand		
	Coef.	t-test	Marg. effects	Coef.	t-test	Marg. effects
Household size	23.33***	5.23	22.54	7.10*	1.76	6.76
Household size squared	−0.53***	−3.04	−0.51	0.22	1.37	0.21
Gender	1.32	0.07	1.28	−25.38	−1.59	−24.16
Ratio of children to adults	−5.78	−0.55	−5.58	−3.89*	−1.82	−3.70
Expenditure	0.03***	2.60	0.03	0.02***	2.69	0.02
Population	−3.04*	−1.77	−2.94	−6.42**	−1.98	−6.11
Occupation	−58.30***	−4.50	−56.31	−78.37***	−7.65	−74.62
Education	−10.05***	−2.59	−9.71	2.25	0.73	2.14
Time for fetching water in dry season	−0.02	−0.63	−0.02	0.08***	4.81	0.07
Access to public well	15.20	1.11	14.68	−10.72	−1.07	−10.20
Access to public pump	−10.18	−0.85	−9.83	13.58*	1.84	12.93
Access to own opened well	31.59**	2.00	30.52	–		
Access to other opened well	23.02	1.53	22.24	–		
Price	–			−2.15	−1.02	−2.05
Constant	43.87*	1.82	–	83.64***	3.94	–
Variance $\sigma_1^{2\,a}$	71.31***	24.16				
Variance $\sigma_2^{2\,a}$	70.03***	18.39				
Corr. coef. ρ_{12}^{a}	−0.48**	−2.06				
$\chi^2(\text{df} = 12)$	314.80***					
Log-likelihood	−2,484.69					
Observations	325					

Own results

*$p < 0.10$, **$p < 0.05$, ***$p < 0.01$

[a]These are the elements of the variance-covariance matrix Ω (Eq. 3)

independent variables included in our regression models. Multicollinearity is thus not expected to be a problem in the estimation.

Finally, some of the independent variables in the system (2) might be endogenous; that is, they are influenced by some of the same variables that determine water demand. For instance, although wealth, education and access to own wells are explanatory variables of water demand, it can be expected that access to own wells and education are influenced by wealth. If these were true, access to own wells and education will be endogenous, leading to inconsistency of the SURT estimates. However, based on IV techniques and the Durbin–Wu–Hausman test, we found that access to own wells and education were exogenous variables in these data and can be directly used in the estimation as explanatory variables. For both variables, Durbin–Wu–Hausman tests on first-stage residuals were not significantly different from zero (at the 10% level). Additionally, the R-square of the first stage of the IV estimation were very low (less than 0.10). Although these results implied that the variables access to own wells and education are exogenous, they did not show that the estimations were completely free of endogeneity problem. Rather these results indicated that the endogeneity effects on the SURT estimates in both rainy and dry seasons are expected to be insignificant.

4.2 Water Demand in the Rainy Season

The estimation results for water demand in the rainy season are presented in Table 3. The coefficient of the time for fetching water is significant and carries a negative sign, as expected, for both free and purchased water demand. This indicates that the more time needed to travel to and wait at the source, the lower the water consumption. The average marginal effect of time for fetching free water is estimated at −0.17. This implies that, for every extra minute that a household must spend in fetching water in the rainy season, it consumes 0.17 l less. This reduction is quite reasonable and might be attributable to the high opportunity cost of labor in the rainy season. This result underscores the need for a dense network of improved water facilities to guarantee sufficient and safe levels of household water use.

As expected, water price was negatively related to water consumption for households that use purchased water and those that use both free and purchased water. Nevertheless, the coefficient of this variable is not significant. Moreover, own-price elasticity is lower and estimated at −0.15 [i.e., $-1.65 \times (7.24/82.04)$]. This value is consistent with other findings in developing countries. For instance, Zekri and Dinar (2003) found a price elasticity of −0.24 for a low-revenue population in rural Tunisia. In contrast, other studies have obtained higher elasticity, especially in areas where water is currently delivered by vendors at a high price (e.g., Acharya and Barbier 2002). In these respects, our estimate is quite reasonable for a population without access to private improved water sources and with low water prices. This result indicates that purchased water demand is highly or even perfectly price inelastic. This implies that rural households, especially those using either purchased water or both free and purchased water, are very insensitive to changes in water price. The perfect own-price inelasticity of water cannot be explained here by only the necessity nature of water. A likely reason is that households are willing to pay more, at least in the short run, for water supply improvement due to its scarcity in the study area. This finding confirms that domestic water problems are a major concern in the study zone and reveals the population's awareness of these problems.

Unsurprisingly, household size positively affects both free and purchased water demand. This implies that the larger the household, the greater its water consumption. However, we found that, in the free water demand model, the relationship between household size and water use took a quadratic form with an inverted-U-shaped curve. Additionally, in the model of purchased water demand, the marginal effect of household size was only 4.74. These results show that water consumption increases with household size, but at a diminishing rate. This implies a scale effect of household size on water consumption, i.e., the larger the household, the lower the per capita consumption. This can be explained by the economies of scale of certain domestic activities, such as cooking and washing dishes as well as cleaning house. Looking more closely at household composition, our results show that an increase in the number of children in a household reduces per capita water use. Although its coefficient is not significant in the free water equation, the variable ratio of children to adults has a negative sign in both the free and purchased water demand equations. This seems to show that a child uses less water than an adult. However, in the study area, where children are used to playing in unhygienic environments, more water is needed to ensure child hygiene. As has been found elsewhere for hand-washing programs (HDR 2006), it is likely that increasing water use for child hygiene will help to reduce the high morbidity rate observed in rural Benin (130‰ child diarrhea morbidity in 2001) (INSAE and ORC Macro 2002).

The consumption of free or purchased water depends on the accessibility of water sources. Households that have access to private (one's own or neighboring) traditional sources tend to use more free water, and similarly, households that have access to public pumps consume more purchased water. The marginal effect implies that access to one's own and neighboring private opened (unprotected) wells increases daily consumption of free water by 41 and 30 l, respectively. Although access to opened wells increases water consumption, the quality of water from these opened sources is very low, as observed elsewhere by Gorter et al. (1995). Indeed, these unimproved wells with surface water and without a cement cover are particularly susceptible to microbial contamination (Gorter et al. 1995) and are sources of waterborne diseases. This is also in line with the population's perception in 65% of the surveyed villages.

4.3 Water Demand in the Dry Season

As shown in Table 4, both free and purchased water consumption in the dry season were positively related to household asset expenditure, a variable found to be a good proxy for wealth in rural areas. This result supports our initial hypothesis of a positive relationship between wealth and water use and can be explained in two ways. First, the difference in water use for activities such as cooking and washing between better-off and poor people may be important since poor people cook either less often or rarely and have less clothing to wash. Second, better-off people can afford the higher cost associated with fetching water in the dry season. In fact, we have seen in the study area that better-off people may travel long distances by motorcycle to fetch water. This result clearly implies that poverty reduces water use.

In the free water demand model, the relationship between the total time for fetching water and water consumption is not significant. This demonstrates that free water consumption will not be significantly reduced due to an increase in the time required to fetch it. This may be explained by the high level of water scarcity in the dry season. Contrary to a priori expectations, the time required for fetching positively affects purchased water demand. This result implies that the quantity of purchased water used increases with the time required for fetching water. A plausible explanation is a change in water use patterns: households mostly wash clothes and bathe at the water sources in the dry season. The large amount of time required for fetching water is, therefore, used basically for washing activities, and this may require using more water.

Village population carries a negative sign and is significant for free and purchased water at the 10% and 5% levels, respectively. This shows that people in villages with more inhabitants consume less water. This supports our initial hypothesis. Indeed, we have seen in the study area that people in some villages can only take a fixed quantity of water in order to allow everybody to have at least a minimum ration of water. With a high population, household members may thus queue several times before accumulating the desired quantity. The marginal effects are −2.94 and −6.11 for free and purchased water, respectively. Thus, an increase of the population by 1,000 persons will, ceteris paribus, lead to a decrease of about 6 l in daily household consumption of purchased water. This result is quite interesting since it can be used to forecast the effect of population growth on water use or scarcity. In fact, the rate of population growth (3.25%) in the study area is one of the highest in the world.[10]

4.4 Comparison of Water Use Determinants Between Seasons

The difference in water use between the rainy and dry seasons is not only a matter of variation in quantity; differences in determinants were also observed. A comparison of the results in Tables 3 and 4 reveals that time spent for fetching water, access to water sources and household asset expenditure were the most important variables that differently affected water use in the rainy and dry seasons. For instance, time for fetching water had a negative effect on free water use in both the rainy and dry seasons as mentioned earlier, but the effect was not the same across the two seasons—it was larger in the rainy season and smaller in the dry season. The marginal effect of time spent for fetching free water was, in fact, eight times larger in the rainy than in the dry season. This difference in marginal effects can be explained by both the higher level of water scarcity and lower opportunity cost of labor in the dry season, as compared to the rainy season.

Also noteworthy is access to water sources, which affected water use differently in the rainy and dry seasons. While access to public wells affected both free and purchased water in the rainy season as expected, it had no significant effect in the dry season. Water availability from these sources is erratic in the dry season because, during this period, only water from deep aquifers is available, and the public wells penetrate only into the medium aquifers. Rural population also perceived that the low availability of water in public wells is due to their low depth. A possible solution might be to dig deeper wells, but this will increase not only the drilling cost, but the extraction cost as well, especially in the dry season. Deeper wells must also be equipped with manual or submersible pumps to reduce the human effort required for the water extraction. In fact, a water management policy based on groundwater will always face high extraction costs during the dry season due to the low level of groundwater. However, to reduce pumping costs and the impact of low groundwater levels on water supply, a sustainable water policy based on groundwater can be adopted by supplementing the unmet demand with surface water through investments in infrastructures for tapping and treating surface water.

The effect of wealth status on water use behavior also varied between seasons. While the effect of poverty on water use was observed only for free water during the rainy season, this effect was significant in the dry season for both free and purchased water. This is likely due to the fact that the lack of farm activities in the dry season tends to exacerbate poverty and thus increases the disparity between the better-off and poor, in terms of not only food shortages but also water use. Finally, access to either one's own or a neighboring private well significantly increased free water use in the rainy season but had a smaller impact in the dry season. Alternatively, it might be expected that better-off people are likely to invest more in private wells. If this was true, access to own well would be endogenous. However, as it has been shown earlier, access to own well is exogenous in these data.

[10] Average annual population growth was 2.5% in Sub-Saharan Africa and 2.2% in low-income countries between 2001 and 2007 (World Bank 2008).

5 Conclusion and Policy Implications

The objective of this study was to analyze factors affecting domestic water use among rural households without access to private improved water sources. We also investigated the seasonal variation in the determinants of water use.

The results showed that water demand from purchased sources is price inelastic in the rainy and dry seasons. This indicates that rural households in Benin are less sensitive to increases in water price, and higher prices will not lead to a significant decrease in water use. This implies that households are willing to pay more for a safe and reliable water supply. This can be explained here by the high level of water scarcity. A policy implication is that water projects based on the principle of generating revenue from water sales to maintain and manage a water system are likely to be feasible in the study area. However, we suggest that the participation of the rural population should not be restricted to financial contributions. They should also be involved in the choice of water system and its management.

We found that the time required for fetching water negatively affects water demand. This might be explained by the high opportunity cost of allocating labor for fetching water, especially in the rainy season. The rainy season is the period of farm activities, which represent the main source of income. Therefore, a water policy intended to reduce the time required for fetching water will likely lead to an increase in the time allocated for productive activities, such as agricultural production. This shows that water supply improvements might be of great importance to the population's welfare and poverty reduction. One policy implication is to design and implement a dense network of improved water systems (e.g., drilled wells that penetrate into the deep aquifers and equip either with manual and submersible pumps) to achieve a sufficient level of safe water use by the households. In addition, the analyses showed that poverty reduces water use. This implies that poverty reduction and development policies in rural areas should include an objective of water supply improvement.

Overall, it is clear that different socioeconomic variables, such as household size and composition, access to water sources, wealth and time required for fetching water, are the most important determinants of water demand. This is unsurprising since it is consistent with economic theories and other findings for developing countries (e.g., Sandiford et al. 1990; Keshavarzi et al. 2006). Moreover, this study has revealed that the effects of these determinants vary not only between household types, but also between the rainy and dry seasons. Time for fetching water, access to water sources and wealth were found to be important variables that differently determine water use between seasons. These factors will help to better evaluate possibilities and constraints in the improvements of rural water supplies. Therefore, they must be considered by policy makers for the planning and implementation of rural water projects in order to assure the acceptability and maintenance of improved systems.

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