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Demand for Piped and Non-piped Water Supply Services: Evidence from Southwest Sri Lanka

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Abstract In many countries water supply is a service that is seriously underpriced, especially for residential consumers. This has led to a call for setting cost recovery policies to ensure that the tariffs charged for water supply cover the full cost of service provision. Identification of factors driving piped and non-piped water demand is a necessary prerequisite for predicting how consumers will react to such price increases. Using cross-sectional data of 1,800 households from Southwest Sri Lanka, we estimate water demand functions for piped and non-piped households using appropriate econometric techniques. The (marginal) price elasticity is estimated at -0.15 for households exclusively relying on piped water, and at -0.37 for households using piped water but supplementing their supply with other water sources. The time cost elasticity for households relying on non-piped water only is estimated at -0.06 on average, but varying across sources. For both piped and non-piped households, we find evidence of substitutability between water from different sources. We discuss the implications of these results in terms of pricing policy.

Keywords Demand estimation · Household water use · Piped and non-piped water services · Price elasticity · Pricing policy · Sri Lanka

1 Introduction

In many countries water supply is a service that is seriously underpriced, especially for residential consumers. This has led to a call for setting cost recovery policies to ensure that the tariffs charged cover the full cost of service provision. A detailed knowledge of the structure

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of water demand of piped and non-piped households is thus essential for planning purposes. It helps predict the impact on consumers' demand and welfare of any policy involving some change in tariffs and/or income for the household. Using cross-sectional data of 1,800 households from Southwest Sri Lanka, we estimate water demand for piped and non-piped households using appropriate econometric techniques.

The present paper contributes to the still short literature on residential water demand in developing countries.[1] Using household survey data from 17 cities in Central America and Venezuela, Strand and Walker (2005) derive price elasticities for piped and non-piped households equal to −0.3 and −0.1, respectively. Nauges and Strand (2007), using the same dataset, estimate water demand of non-piped households in four cities in El Salvador and Honduras. They found non-tap water demand elasticities with respect to total water cost (defined as the sum of water price and collection time costs) of between −0.4 and −0.7. Basani et al. (2008), using cross-sectional household-level data from seven provincial Cambodian towns, estimated the price elasticity of water demand of connected households to lie in a range between −0.4 and −0.5. The only study who found evidence of a price elastic water demand is Rietveld et al. (2000) using data for connected households from Indonesia (price elasticity has been estimated at −1.2).[2]

Estimation of household water demand functions in developing countries remains scarce for the main reason that necessary data are not always available. First, water consumption may not always be metered. Second, because the conditions of access and actual use of water sources vary in general across households (especially in urban areas), well-designed household surveys are needed.[3] In particular, information on the conditions of access to each water source (price, distance to the source, quality, reliability, etc.) are necessary (see Mu et al. 1990, for related discussions).

In this article, we estimate water demand for piped and non-piped households using data from a survey of 1,800 households conducted in Sri Lanka in August–October 2003. Because of almost universal metering of households with piped water connections, the consumption data have a high degree of accuracy that is not often found. In addition, the dataset is complemented by a large set of socioeconomic and health variables. The main contribution of this article is to provide measures of substitutability/complementarity between water sources for both piped and non-piped households, through the estimation of systems of simultaneous water demand equations. This approach allows for water to be considered a heterogeneous good and provides measures of direct and cross-price elasticities. We control for the simultaneity between choice of water source and choice of quantity by estimating the probability of households to have a connection to the piped network. A Tobit approach is used to deal with censored observations in the system of water demands. As far as we know, this approach is novel in this literature.

Section 2 describes the background and data. In Sect. 3, we discuss the specification of the water demand models. Estimation strategy and estimation results are presented in

[1] An extensive empirical literature exists on residential water consumption in developed countries (see Hanemann 1998; Arbués-Gracia et al. 2003, or Dalhuisen et al. 2003 for comprehensive surveys). In developing countries, studies on household water use have been mainly under the form of contingent valuation studies and hedonic price studies to measure household's valuation of improved water services (see among others Whittington et al. 1990; North and Griffin 1993; Daniere 1994; Whittington et al. 2002; Komives 2003; Pattanayak et al. 2006).

[2] Rietveld et al. (2000) are the only authors to use the discrete-continuous model first proposed by Burtless and Hausman (1978) and transposed to the water demand literature by Hewitt and Hanemann (1995).

[3] On the contrary, most analyses from industrialized countries are based on aggregate consumption data provided by water utilities.

Sects. 4 and 5, respectively, while policy implications and conclusions are found in Sect. 6.

2 Background and Data

The population of surveyed households covered three urban districts in Southwest Sri Lanka: Gampaha, Kalutara and Galle. Among the surveyed households, 38% have a private connection to the piped network.[4] These households consume on average about 135 l of water per capita per day from the piped network. The rest of the surveyed households do not have any piped connection and rely on other private or public sources including private well, public tap, public well, water provided by neighbours, vendors and surface water. Households relying on private wells consume on average 185 l per capita per day, more than twice the amount of water collected on average from community sources: public wells (78 l), neighbours (56 l), and public taps (24 l). About 40% of the piped households in our sample also use water from other sources, mostly from private wells. Piped households consume on average 10 m^3/month from these sources. Getting water from more than one source is also quite common among the population of non-piped households.[5]

Water from the piped network is charged through an increasing five-block tariff.[6] The same tariff applies to all piped households in our sample. The typical or median monthly water bill is SLK 89, while a typical household spends SLK 10,300 on household expenses—suggesting that the costs of piped water supply makes up less than 1% of household expenditure. Consuming non-piped water imposes different types of “costs” on a household, when compared to using the water directly from their private tap. First, the household may spend time to go to the source and wait at the source to obtain the water. Second, water from most non-piped water sources in general involves equipment costs (the household may need to buy equipment to abstract the water such as a hand pump or an electric pump). Third, the household may need to pay a fee to get access to the water, in particular if bought from vendors or community sources. Finally, there is the inconvenience of not having access to piped water as such, including a possible lower quality of the non-piped water. In our sample, walking time for piped households who collect water from a private well or from community sources is on average less than 5 min, whatever the source. The shortest walking time is observed, as expected, for those households who get water from a private well. Only households collecting water from public taps have to wait at the source (7–8 min on average). Households in our sample do not pay any fee for buying non-piped water, whatever the source, but they do pay for installing equipment to obtain access to the source of water. The most common equipment is a bucket and rope followed by hand and electric pumps.

Descriptive statistics on household’s socioeconomic characteristics are presented in Table 1, for both piped and non-piped households (for greater information on survey and data, see Nauges and van den Berg 2007). Mean comparison tests show that piped households in general are characterized by having more household members, higher income, and higher education than non-piped households.

[4] Piped households had to pay SLK 8,415 (equivalent to US $87 in 2003) in order to get a private connection to the piped network (including road cutting, pipe laying, meter installation). This represents about half the monthly wage for a piped household.

[5] The most frequent combination of water sources among the surveyed households is neighbours with private well, public tap with private well, and public well with private well.

[6] Block 1: [1–10 m^3], price is 1.25 SLK/m^3; block 2: [11–15 m^3], 2.50 SLK/m^3; block 3: [16–20 m^3], 6.50 SLK/m^3; block 4: [21–25 m^3], 20.00 SLK/m^3; block 5: [>25 m^3], 45.00 SLK/m^3.

Table 1 Descriptive statistics on households' characteristics

Variables	Non-piped households		Piped households		Mean comparison test[a]	
	Mean	(Std dev)	Mean	(Std dev)	Test-statistic	*p*-value
Household monthly wage (SLK)	13,047	(306)	15,149	(462)	−3.91	0.0001
Total monthly income (SLK)	16,725	(622)	22,259	(2,176)	−3.06	0.0022
Household size	4.68	(0.05)	4.93	(0.08)	−2.80	0.0052
Total number of rooms	3.94	(0.06)	3.98	(0.07)	−0.39	0.6959
Use of a storage tank (0/1)[b]	0.44	(0.01)	0.39	(0.02)	2.09	0.0365
Years of education completed by household's head	8.67	(0.09)	9.29	(0.12)	−4.03	0.0001
Number of households	1,116		602			

[a] For each variable, the null hypothesis is equality of the mean between non-piped and piped households
[b] Indicates a variable taking two values only: 0 or 1

3 Specification of the Water Demand Models

3.1 Structure of the Demand Models

In the literature on water demand, which has been essentially based on data from developed countries, the water demand function of the representative household connected to the piped network is traditionally specified as a single equation of the form:

$$q = f(p, \mathbf{x}), \tag{1}$$

which describes the relationship between piped water consumption (q) on the one hand, and the price of piped water (p) and a vector of household characteristics ($\mathbf{x}$) (to control for heterogeneity of preferences and outside variables affecting water demand) on the other hand. This approach is useful to describe the behaviour of piped households in developed countries where almost 100% of households are connected to the piped network and where substitutes often do not exist. The single-equation approach has also been used by the few authors using data from developing countries, in general to estimate demand for water from a particular source: among other examples, Crane (1994) specifies separate demand equations for Indonesian households supplied by water vendors and for households relying on hydrants; Rietveld et al. (2000) and Basani et al. (2008) estimate a water demand equation for households with a piped connection. The estimation of (single) source-specific demand equations provides insight on variables driving water use from that particular source, such as its own price, quality and accessibility. However, this approach does not allow to measure substitutability/complementarity between water from different sources. In this article, we propose to estimate a system of simultaneous demand equations corresponding to water drawn from different sources. A general system of L water demand equations reads as follows:

$$\begin{cases} q^1 = \sum_{k=1}^{L} \gamma_k^1 p_k + \mathbf{x^1}\boldsymbol{\beta^1} + u^1 \\ \vdots \\ q^L = \sum_{k=1}^{L} \gamma_k^L p_k + \mathbf{x^L}\boldsymbol{\beta^L} + u^L \end{cases} \tag{2}$$

where q^k $(k = 1, \ldots, L)$ is water consumption from source k, p^k $(k = 1, \ldots, L)$ is the price [resp. cost of water collection] for piped water [resp. non-piped water] taken from source k, the **x**-vector gathers household's characteristics, and u^k $(k = 1, \ldots, L)$ is the usual idiosyncratic error term.

If consumption and price [cost] are measured in logs, then the coefficient γ_k^k in equation k will measure "direct" price [cost] elasticity of demand for water from source k. The coefficients γ_k^j for $j \neq k$ will provide a measure of "cross"-price elasticity, i.e., by how much will consumption of water from source j change if the price [cost] of water from source k increases. We expect negative direct price and cost elasticities and positive cross-price elasticities (since we expect that water from different sources are substitute rather than complement).

In what follows, we estimate two systems of simultaneous water demand equations. In our sample, about 40% of the piped households combine water from the piped network with water from other sources, mostly from private wells. We thus estimate, for the sub-sample of piped households, a system of two equations combining water from the piped network with water from non-piped sources. In the group of non-piped households, the most frequent case is households combining water from a private well with water from neighbours. We thus estimate a system of two simultaneous demand equations, one for each of these two sources.

3.2 Measurement of Price and Cost

Explanatory variables in water demand models commonly include water price, income, and household demographic and socioeconomic characteristics. Some discussion is needed here regarding the specification and measurement of the price variable for piped and non-piped water. For all households in our sample water from the piped network is sold under the same five-block increasing tariff, and all piped households have to pay a fixed fee of SLK 50, whatever their monthly consumption. Homogeneous pricing in our sample makes it impossible to estimate water demand using the (theoretically consistent) two-step approach describing the choice of the block (first step) and the choice of consumption inside the block (second step), along the lines of Hewitt and Hanemann (1995). Instead, we follow the instrumental variables (IV) approach which has been commonly used in the water demand as well as in the labor supply and energy demand literature (Agthe et al. 1986; Deller et al. 1986; Nieswiadomy and Molina 1988, 1989). The use of instruments for the price variable (in a two-stage least squares framework) allows to get unbiased estimates of the price coefficient in the demand equation. The main drawback of this approach tough, is that the interpretation of the price coefficient as a price elasticity is conditional on the household remaining within the observed block of consumption (Olmstead et al. 2007).

In the context of IV estimation, the econometrician has to make a decision regarding the price variable to consider in the water demand models. If theory advocates the use of marginal price (the price of the last cubic meter), average price (computed as total bill divided by total consumption) has however often been preferred. Authors considering average price argue that households are rarely well informed on the price structure and are thus more likely to react to average price than to marginal price.

In the present study, one could argue that average price should be chosen because the water tariff structure is quite complex (it is made of five different blocks, and the fixed fee makes up a large part of the total cost especially for lower-volume users) and so households are less likely to know in which block they are and which marginal price will be charged to them. However, it is also very well possible that households know the marginal price because the price in each block varies significantly (from SLK 1.25/m^3 in the low block (for any unit below 10 m^3/month) to SLK 45/m^3 for any unit above 25 m^3/month), and widespread occurrence of metering assumes that households have (some) control over their consumption.[7] In the following empirical application, we test which price households are sensitive to by testing for the significance of the marginal price and average price in the piped water demand equation.

Costs borne by households collecting water from private wells or community sources have already been discussed (see Sect. 2). Households in our sample do not pay for the daily consumption of non-piped water, whatever the source (public tap, public well, neighbours, etc.); vending of water tends to be virtually non-existent. However households collecting water from these sources have to spend time to go to the source and to wait at the source. One should in theory compute an opportunity cost of time, which would correspond to the (monetary) value of the time spent to get the water for the member of the family in charge of it. Information on who goes to the source is sporadic in the survey and difficult to use.[8] Instead, we consider total time (in minutes) spent to go to the source and to wait there. We believe that using total time instead of the opportunity cost of time is acceptable in this case as the average time spent to go and collect the water is quite short (less than 5 min on average).

4 Estimation Procedure

We estimate two systems of two simultaneous equations, one for the sub-sample of piped households, and one for the sub-sample of non-piped households. Since it is likely that the decision to get a private piped connection was not taken randomly by households, we have to control for selection bias by first estimating a model that explains the decision of households to have (or not) a connection to the piped network. The simultaneity between choice of water source and quantity of water use was first acknowledged by Whittington et al. (1987) and two-step Heckman procedure for selection bias correction has been applied since then in this literature (see, among others, Larson et al. 2006 on data from Madagascar, and Basani et al. 2008 on data from Cambodia).

4.1 Determinants of the Connection Status

The decision of getting a private connection is described using the traditional Probit model. Authors generally agree that both source attributes and household characteristics should enter the choice model. Source attributes account for heterogeneity in water from different sources while household characteristics account for difference in tastes, opportunity cost of time, and perception of health benefits from improved water. The determinants that we consider in this study are: income,[9] household size, number of years of education completed by the head of the household, dummy variables for district, and dummy variables measuring concern about

[7] Distribution graphs of households inside each of the five blocks show that households in the first four blocks tend to choose the "right-end" of the block, while households in the fifth block are gathering around the "left-end" of the block. Such behaviour would be more consistent with a "marginal price perception", since households (in the first four blocks) seem to consume "up to the limit" once they have selected the block of consumption.

[8] The person in charge of collecting water is in most cases not identified.

[9] Income includes estimated total monthly income of all wage earners in the household, plus any other source of income, plus any money that is remitted to the household by a family member working outside the country.

taste, reliability, and safety of water from private wells.[10] Estimated parameters from this first-stage Probit are then used to compute the so-called inverse Mill's ratio that will be added to the water demand models to control for selection bias (Heckman 1979).

4.2 Water Demand of Piped Households

In our sample, all households with a private connection at home consume water from the piped network while 41% complement this consumption with water from extra sources. In most cases (more than 80%), piped households complement their consumption from the network with water from private wells. In what follows, we estimate a two-equation system ($L = 2$) combining demand for water from the piped network (q^1) and demand for water from non-piped sources (q^2). We do not distinguish between the various non-piped sources for the main reason that the number of observations for non-piped sources other than private well is too low. The dependent variable q^2 can take on a value of zero with positive probability, when piped households do not use water from extra sources. Because parameter estimates may be biased if Ordinary Least Squares are used on the sub-sample of positive observations only, we specify the equation for q^2 as a Tobit model for variables censored at zero. More precisely, we follow the approach developed by Shonkwiler and Yen (1999) to control for censoring of observations in a system of equations (see Appendix for greater detail on the estimation technique).

The vector of explanatory variables for the consumption of piped water contains (instrumented) price of piped water (in log), time cost for getting water from non-piped sources (in log), income (in log), number of rooms (in log), number of hours of piped water availability, whether the household has a storage tank (0/1), and district indicators (0/1). The vector of explanatory variables for the consumption of non-piped water includes (instrumented) price for piped water (in log), time cost (in log), household size (in log), income (in log), use of an electric pump (0/1), and district indicators (0/1). As discussed before, the only cost incurred by households getting water from non-piped sources is a time cost (they do not pay any fee per unit of water).

In order to determine to which price piped households are more sensitive to, we estimate two versions of the system of water demands, one with the marginal price, the other one with the average price. Marginal price and average price are, by construction, endogenous in the demand model, and have to be instrumented. Variables correlated with the cost of supplying water (such as population and network density, labour cost, size of network) are possible instruments.[11] Such information is unfortunately not available in our data. We choose household location dummies as identifying instruments for the water price paid by the household. We have 17 such municipality dummies. These dummies are going to be good instruments as long as household's location choice does not depend on the set of available water sources. We believe this to be a reasonable assumption for this particular study area since the set of available water sources (and above all the possible access to the water network) is quite similar across the three districts. Predicted values for the marginal and average prices are then used instead of observed prices in demand models.

[10] Households were questioned about their opinion regarding taste, safety, and reliability of water from each source. From their answers, we build three indicator variables which take the value of 1 if households are concerned about taste, safety, and reliability of water from their private well, and 0 otherwise.

[11] Because the same tariff structure applies to all households (i.e., there is no cross-sectional variation), it is not possible to use the price of each block and the quantity limiting each of the blocks as instruments for the marginal and average prices.

Finally, the decision of households to get a storage tank as well as the decision to buy an electric pump (used as covariates in the demand equations) were certainly codetermined with the expected need for water. However, since these decisions were in most cases made some years ago, we consider that these variables are exogenous to the observed water purchase decision (see Crane 1994 for similar arguments).

4.3 Water Demand of Non-piped Households

In what follows, we assume that access to non-piped sources is exogenous in the water demand model for non-piped households, i.e., that conditions of access to water sources were not the main factor driving household's choice of location in the first place. This assumption, which seems reasonable for this particular case study, allows to estimate water demand separately for different groups of non-piped households. We focus here on those households combining private well and water collected from neighbours (the most frequent case in our sample). We estimate a system of two simultaneous demand equations ($L = 2$). The dependent variables in the system are the log of water consumption from a private well and the log of water collected from neighbours (measured in litres per capita per day).

Right-hand side regressors include time cost (to go to and to wait at the source) for water collected from a private well and water bought from neighbours (in log), household size, income (in log), number of rooms, use of a storage tank (0/1), household's ethnicity (which takes the value of 1 if the household is Sinhalese), concern about taste of water (0/1) for water from both sources, use of a tub well (0/1), and use of an electric pump (0/1). In the demand equation for water collected from neighbours, we also control for the type of access provided by neighbours (private connection or well). Here too, we assume that the decision to buy the equipment to haul water (which was made some years ago) is exogenous to current water consumption.

5 Estimation Results

To avoid extreme values in the distribution of water consumption per capita, we cut the distribution (of total water consumption per capita) above the 5th percentile and below the 95th percentile.

5.1 Determinants of the Connection Status

Maximum-likelihood estimation results for the Probit model describing household's connection status are presented in Table 2.

The model is estimated on the full sample (1,794 households). Overall fit of the model is satisfactory, providing 66% of correct predictions. Estimated coefficients are almost all significant and have the expected sign. Households receiving a higher income, households with a more educated head, and larger households are more likely to have a private connection. These results confirm previous evidence that households with higher income and better education are usually more willing to get improved water services (Madanat and Humplick 1993; Hindman Persson 2002; Larson et al. 2006; Nauges and Strand 2007; Basani et al. 2008). Finally, the dummy variable describing concern about reliability of water from private well has the expected positive sign and is significant: the more concerned the household is about reliability of water from the private well, the higher the probability that she gets a private connection to the piped system. Concerns about taste and safety of water from private

Table 2 Estimation of the probability to have a connection to the piped network (Probit model): maximum likelihood estimation results

List of variables	Coef.	Std. Err.	P>z
Dependent variable: probability of having a private connection			
Constant	−1.3142	0.1403	0.0000
Income[a]	0.0024	0.0012	0.0520
Household size	0.0335	0.0174	0.0550
Education of the head[b]	0.0463	0.0104	0.0000
Concern about taste of water from private well (0/1)	0.1405	0.0971	0.1480
Concern about safety of water from private well (0/1)	−0.0961	0.1330	0.4700
Concern about reliability of water from private well (0/1)	0.3459	0.1962	0.0780
Negombo district (0/1)—*reference*	–	–	–
Kalutara district (0/1)	0.5659	0.0798	0.0000
Galle district (0/1)	0.6746	0.0714	0.0000
Number of observations	1,794		
Likelihood-ratio test: test statistic (p-value)	143.34	(0.000)	
Percentage of correct predictions	66%		

[a] Income includes estimated total monthly income of all wage earners in the household, plus any other source of income, plus any money that is remitted to the household by a family member working outside the country. Income is measured in SLK 1,000
[b] Number of years of education completed

well are not found significant in this model. From the estimated parameters we compute the inverse Mill's ratio which will be added to the water demand models to control for potential selection bias.

5.2 Estimation of Water Demand of Piped Households

We present here estimation results for the two-equation system combining demand for piped water and demand for non-piped water. Estimation is made on the sub-sample of piped households, which amounts to 495 observations overall. Simple tests of the significance of price coefficients show that piped households in our sample are sensitive to marginal price[12] and specification tests have shown that the price elasticity of piped water demand was different for piped households using piped water only and piped households combining piped water with water from extra sources. Tobit estimation results for the two-equation system are shown in Table 3.

Marginal price elasticity of piped water demand is estimated at −0.37 (significant at the 1% level) for piped households combining piped and non-piped water and at −0.15 (significant at the 1% level) for piped households using piped water only. A 10% increase in the price of piped water would thus induce a decrease in piped water consumption by 3.7% and 1.5%, respectively. As expected, the higher the time cost to get to non-tap sources, the higher the consumption from the piped network. Income elasticity is estimated at 0.14. Households living in a house with a greater number of rooms use on average more water per capita. Households who get more convenient access to piped water through increased water pressure (presence of a storage tank) and who enjoy piped water for a greater number of hours, consume on average more water per capita. Having a storage tank in the house

[12] Estimation results for the instrumentation of marginal price are not shown here but are available from authors upon request.

Table 3 Sub-sample of piped households. Tobit estimation of a system of water demands

	Coef.	Std. Err.	P>z
Dependent variable: piped water consumption, per capita per month (log)			
Constant	0.3879	0.3913	0.3220
Instrumented marginal price (log) for households combining piped and non-piped water	−0.3682	0.0771	0.0000
Instrumented marginal price (log) for households using piped water only	−0.1507	0.0556	0.0070
Time cost (log)	0.1001	0.0247	0.0000
Income (log)	0.1375	0.0454	0.0020
Number of rooms (log)	0.3213	0.0666	0.0000
Number of hours of piped water availability	0.0152	0.0037	0.0000
Household has a storage tank (0/1)	0.1239	0.0551	0.0250
Negombo district			
Kalutara district	−0.2036	0.1251	0.1040
Galle district	−0.0513	0.1355	0.7050
Mill's ratio	0.3111	0.2396	0.1940
Number of observations	495		
Adjusted R^2	0.23		
Dependent variable: non-piped water consumption, per capita per month (log)			
Constant	0.6599	0.3075	0.0320
Instrumented marginal price of piped water (log)	0.2524	0.1425	0.0760
Time cost (log)	−0.4436	0.0417	0.0000
Household size (log)	−0.6230	0.2042	0.0020
Income (log)	−0.0628	0.0906	0.4880
Household has an electric pump (0/1)	0.9678	0.2024	0.0000
Negombo district			
Kalutara district	0.0370	0.1844	0.8410
Galle district	−0.0054	0.1948	0.9780
Mill's ratio	−0.1310	0.3635	0.7190
κ (see Eq. A4 in Appendix)	−0.1453	0.2213	0.5120
Number of observations	495		
Adjusted R^2	0.36		
Breusch-Pagan test of residuals independence: 4.491 (p-value: 0.0341)			

is found to increase monthly per capita consumption by 13% on average.[13] An extra hour of piped water availability would increase monthly per capita consumption by 1.5%. The district dummies are not found significant in this model (Negombo district is the reference).

As far as non-piped water consumption is concerned, we find a significant elasticity to time cost. This elasticity is negative and estimated at −0.44. A higher marginal price of piped water increases consumption of non-piped water, which is evidence for substitutability between piped and non-piped water. Non-piped water is found to be an inferior good as non-piped water consumption is found to be negatively related to income (but non-significant). The result that the income effect is positive for piped consumption only is not surprising, though. It indicates that wealthier piped households are less likely to substitute piped water with water drawn from non-piped sources. The coefficient of (log of) household size is found negative and significant, which confirms that the larger the household, the lower per capita

[13] Having a storage tank increases the log of per capita consumption by 0.1239 m^3. This corresponds to an increase in per capita consumption of $[\exp(0.1239) - 1] = 0.13$ or 13%.

water use. Ownership of an electric pump has a strong effect on non-piped water use. The system has been re-estimated without the variables “use of a storage tank” and “use of an electric pump”. The new set of estimates was found to be qualitatively and quantitatively very close to the set of estimates that is reported here. The coefficient of the inverse Mill’s ratio is not found significant in any of the two equations, which would suggest that there is no selection bias in this model due to the connection status (the same result was obtained by Basani et al. 2008 on data from Cambodia). We also considered some other explanatory variables such as cost of operating the equipment, education level or household’s opinions about the piped water service. None of these variables have a significant influence on water consumption per capita. The survey also includes data on house assets (kitchen assets, toilets) and materials used for building the house. Most of these variables were collinear with income and, for that reason have been taken out of the demand equation. The Breusch-Pagan test rejects (at the 5% level) the null hypothesis that residuals from the two equations are independent.

Price and income elasticities derived for piped households in our sample are in the range of elasticities estimated in other regions: Central America (see Strand and Walker 2005 and Nauges and Strand 2007) or Cambodia (Basani et al. 2008). These elasticities are also found quite similar to those estimated in developed countries in the sense that they confirm a low price elasticity of piped water demand (i.e., a price elasticity which is less than one in absolute terms). Our analyses however provide new evidence about the behaviour of piped households who combine piped water with non-piped water. We find evidence that piped water demand of households with access to other water supply sources is more price elastic than water demand of households relying on the piped system only. We show that non-piped water (which is judged good and safe by a vast majority of the surveyed households) is used as a substitute for piped water when there is not a continuous service from the piped network, when piped households are closer to the alternative source (i.e., less time is required to collect water or they own a private well), and when they own more efficient equipment to collect water (i.e., less effort is required to collect the same amount of water). Such effects could not have been identified from the estimation of a single source-specific water demand equation.

5.3 Estimation of Water Demand of Non-piped Households

The system is estimated using the Seemingly Unrelated Regression Estimator (SURE) on the sub-sample of 161 households combining water from a private well and water bought from neighbours. Estimation results are shown in Table 4.

The four coefficients measuring the impact of the cost of time on water consumption are significant in this model. The negative time cost elasticity and the positive cross time cost elasticity illustrate substitution between water from the private well and water provided by neighbours: the more time needed to get water from a source, the lower the consumption from that source and the higher the consumption from the alternative source. Income elasticity (about 0.20) is found significant in both equations. Household size is highly significant in the two equations. The negative coefficient illustrates scale effects in water use (the larger the family, the lower per capita consumption). The size of the house has a positive and highly significant effect on water consumption from the private well. Being able to store water does not have any significant effect on water consumption, whatever the source. The variables measuring households’ concern about taste are not found significant in any of the equations, probably because a vast majority of non-piped households collecting water from private well or getting water from neighbours declared to be satisfied of water quality. The use of an electric pump in the equation fitting water consumption from private well is not

Table 4 Estimation of water demand for non-piped households combining water from private well with water from neighbours (seemingly unrelated regression estimator)

	Coef.	Std. Err.	p-value
Dependent variable: water collected from a private well, per capita per day (log)			
Constant	4.7657	0.3890	0.0000
Time cost for collecting water from private well (log)	−0.0983	0.0260	0.0000
Time cost for collecting water from neighbours (log)	0.0706	0.0381	0.0640
Household size	−0.2174	0.0352	0.0000
Income (log)	0.1916	0.0929	0.0390
Number of rooms	0.1229	0.0350	0.0000
Household has a storage tank (0/1)	0.1792	0.2858	0.5310
Sinhalese household (0/1)	−0.3869	0.2034	0.0570
Tub well (0/1)	−0.2294	0.1597	0.1510
Taste concern (neighbours) (0/1)	−0.1895	0.2470	0.4430
Taste concern (private well) (0/1)	−0.1179	0.1273	0.3540
Household uses an electric pump (0/1)	0.0650	0.2979	0.8270
Mill's ratio	−0.1762	0.3216	0.5840
Number of observations	161		
Adjusted R^2	0.37		
Dependent variable: water collected from neighbours, per capita per day (log)			
Constant	2.0977	0.4043	0.0000
Time cost for collecting water from private well (log)	0.0653	0.0272	0.0160
Time cost for collecting water from neighbours (log)	−0.3385	0.0397	0.0000
Household size	−0.2315	0.0366	0.0000
Income (log)	0.2247	0.0974	0.0210
Number of rooms	0.0389	0.0362	0.2830
Household has a storage tank (0/1)	0.0643	0.2978	0.8290
Sinhalese household (0/1)	0.2133	0.2291	0.3520
Taste concern (neighbours) (0/1)	−0.1763	0.2565	0.4920
Taste concern (private well) (0/1)	0.0563	0.1353	0.6770
Neighbour provides connection (0/1)	0.2208	0.2544	0.3850
Neighbour provides well (0/1)	0.2461	0.1757	0.1610
Household uses an electric pump (0/1)	−0.1774	0.3139	0.5720
Mill's ratio	0.1258	0.3499	0.7190
Number of observations	161		
Adjusted R^2	0.46		

significant. In the second equation, households are found to have, on average, a higher per capita consumption when neighbour provides access to a private well (instead of providing access to a tap connection). The latter is significant at the 20% level. For the first time, we find a significant effect of the variables indicating ethnicity. Sinhalese households are found to have a significantly lower per capita consumption from private wells, all other things equal. The inverse Mill's ratio is not significant in this model.

6 Conclusions and Policy Implications

In Sri Lanka, as in many other developing countries, the utility is charging tariffs that are substantially below the full cost of service. The lack of cost recovery results in low quality services and lack of expansion of the network. In Southwest Sri Lanka, large tariff increases would be needed to ensure that the water utility can recover its full costs and expand its network in the long run. This study provides some indications on the behaviour of piped and non-piped water consumers in this region. First, it confirms the main finding of earlier analyses that piped as well as non-piped water demand is inelastic to its price. It also provides new evidence on substitutability between sources for both piped and non-piped households. Our results indicate that tariff increases may induce piped households with access to non-piped sources to substitute water from the piped network with water from these other sources, in particular when piped households have an easy access to an extra source (a private well for example). This substitution effect is found to be reduced for households with a higher income.

Substitution between water sources is inherent to developing countries where households, in urban areas in particular, may get water from a set of water sources. Substitution between sources is even more likely to occur where, as is the case in Southwest Sri Lanka, piped water services are not fully reliable (41% of piped households in our sample complain about piped water being available less than 24 h a day) and where the quality of non-piped sources is satisfactory in general. In some sense, our results are consistent with Pattanayak et al. (2006) who show, using data from the same region, that easy access to alternative water sources dampens the willingness to pay for improved piped water services.

Our study finally shows that income elasticity is quite low, indicating that consumption volume is not a very good proxy for household's wealth. As such, consumption blocks as used in the current tariff structure in this part of Sri Lanka may not be a very good instrument for targeting subsidies to the poor (see Boland and Whittington 2000, for related discussions).

Appendix

For a piped household, the two-equation system combining demand for piped water (q^1) and demand for non-piped water (q^2) is written:

$$\begin{cases} q^1 = \gamma_1^1 p_1 + \gamma_2^1 p_2 + \mathbf{x}^1\boldsymbol{\beta}^1 + u^1 = \mathbf{w}^1\mathbf{a}^1 + u^1 \\ q^2 = \gamma_1^2 p_1 + \gamma_2^2 p_2 + \mathbf{x}^2\boldsymbol{\beta}^2 + u^2 = \mathbf{w}^2\mathbf{a}^2 + u^2. \end{cases} \tag{A1}$$

Consumption of water from non-piped sources is zero for some piped households. We assume that there exits a latent variable (d^*) describing the decision of piped households to complement their consumption from the piped network with water taken from non-piped source, where $d^* = \mathbf{zb} + \upsilon$. The decision model is written:

$$d = \begin{cases} 1 \text{ if } d^* > 0 \\ 0 \text{ if } d^* \leq 0. \end{cases}$$

To control for censoring of observations, we estimate the unconditional mean of q^2 defined as follows

$$\begin{aligned} E\left(q^2\right) &= P\left(q^2 > 0\right) \times E\left(q^2 \left| q^2 > 0\right.\right) + P\left(q^2 = 0\right) \times 0 \\ &= P\left(q^2 > 0\right) \times E\left(q^2 \left| q^2 > 0\right.\right), \end{aligned} \tag{A2}$$

see Shonkwiler and Yen (1999).

We make the following assumption on the idiosyncratic error term in the equation describing consumption of non-piped water:

$$u^2 \left| w^2, z \right. \sim \text{Normal}\left(0, \sigma_{u^2}^2\right).$$

This gives:

$$E\left(q^2 \left| w^2, \mathbf{z}\right.\right) = \Phi\left(\mathbf{zb}\right)\left(\mathbf{w}^2\mathbf{a}^2\right) + \kappa\phi\left(\mathbf{zb}\right), \tag{A3}$$

where $\Phi(\mathbf{zb})$ and $\phi(\mathbf{zb})$ are, respectively the univariate standard normal cumulative distribution and probability density functions computed over Probit results. κ is an unknown parameter to be estimated.

Based on the latter equation, the system of water demand equations can be rewritten as

$$\begin{cases} q^1 = \gamma_1^1 p_1 + \gamma_2^1 p_2 + \mathbf{x}^1 \boldsymbol{\beta}^1 + u^1 \\ q^2 = \Phi(\mathbf{zb}) \left(\gamma_1^2 p_1 + \gamma_2^2 p_2 + \mathbf{x}^2 \boldsymbol{\beta}^2\right) + \kappa\phi(\mathbf{zb}) + \xi. \end{cases} \quad \text{(A4)}$$

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