# Estimation of Water Demand in Developing Countries: An Overview


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**Abstract**

A better understanding of household water use in less developed countries (LDCs) is necessary to manage and expand water systems more effectively. Several meta-analyses have examined the determinants of household water demand in industrialized countries, but little effort has been made to synthesize the growing body of literature evaluating household water demand in LDCs. This article reviews what is known and what is missing from that literature thus far. Analysis of demand for water in LDCs is complicated by abundant evidence that, contrary to what is observed in most developed countries, households in LDCs have access to and may use more than one of several types of water sources. We describe the different modeling strategies that researchers have adopted to estimate water demand in LDCs, and discuss issues related to data collection. The findings from the literature on the main determinants of water demand in LDCs suggest that despite heterogeneity in places and time periods studied, most estimates of own price elasticity of water from private connections are in the range of –0.3 to –0.6, close to what is usually reported for industrialized countries. The empirical findings on household water source decisions are much less robust and should be a high priority for future research.

## Introduction

This article reviews what is known and what is missing from the growing body of literature on household water demand functions in less developed countries (LDCs). We also discuss the challenges researchers face in carrying out studies of household water demand in the constrained data environment of developing countries, and how these can be overcome.

Studies of residential water demand in industrialized countries have mainly concerned measurement of price and income elasticities. In these countries almost all households have a connection to the piped water network, and tap water, generally of good quality, is the primary source for all water uses. These characteristics permit a relatively straightforward estimation of the household water demand function. The chief methodological issue that has been extensively discussed in this literature is the nonlinearity of the pricing scheme, which may cause endogeneity bias at the estimation stage.

Analyses of household water demand in LDCs first appeared in the work of White and others (1972), Katzman (1977), and Hubbell (1977) but remain limited even today. One reason for this lack of attention is that analyses of household water demand in LDCs are more difficult to do. This is mainly because conditions surrounding water access often vary across households, and this variability makes it almost impossible to base a comprehensive analysis of household water demand on secondary data from the water utility. Households often rely on a variety of water sources, including piped and nonpiped sources with different characteristics and levels of services (price, distance to the source, quality, reliability, etc.). For many households in LDCs water is a heterogeneous good, which is not usually the case in industrialized countries (Mu and others 1990). Obtaining water from nontap sources outside the house involves collection costs that need to be taken into account to assess household behavior accurately.

Researchers have employed four principal strategies to obtain the information needed to investigate household water demand behavior in LDCs. First, well-designed household surveys can be used to complement existing data from public (and private) utilities.[1] Second, households can be asked questions about how they would behave in hypothetical water use situations (e.g., Whittington and others 1990a; The World Bank Water Demand Research Team 1993 and Whittington and others 2002). Third, researchers can look to secondary markets such as housing to draw inferences about how households value improved water services (e.g., North and Griffin 1993, Daniere 1994, and, for a review, Komives 2003). Fourth, experimental methods (including randomized controlled trials) can be used to test how households behave in response to different water supply interventions (Kremer and others 2007, 2008).

This paper reviews the literature that uses data from utilities and household surveys to estimate household water demand functions, not papers that investigate water demand behavior based on stated preference techniques, revealed preference techniques, or experimental methods. We begin with an overview of three large groups of households in LDCs and discuss why water planners need somewhat different information about household water demand behavior to address the policy challenges each household group poses. We then provide a brief overview of the literature on the estimation of water demand functions in industrialized countries because research based on data from LDCs has been informed by findings from this work. Methodologies developed to correct for price endogeneity under nonlinear pricing have in particular been applied in recent studies of household water demand functions in LDCs.

Next we describe the different modeling strategies that researchers have adopted to estimate water demand functions in LDCs, and discuss issues related to data collection. We then review the findings from the literature on the main determinants of water demand functions in LDCs: water price, cost of water collection, quality of water service, and household socioeconomic characteristics. In our conclusions we discuss the policy implications of the findings from this literature and indicate directions for future research. In the Appendix we offer some recommendations for the design of household surveys that collect data to estimate water demand functions.

**Background**

Broadly speaking, there are three large groups of households in LDCs today, each with its own distinct set of water and sanitation challenges. First, there are hundreds of million of households living in the medium and large cities of China, India, Southeast Asia, and Latin America with monthly incomes of US$150-400. Most of these households can now afford municipal piped water services in their homes or will soon be able to do so. For many of these households, full sewerage collection and treatment may remain financially out of reach for some time, but rising incomes will increase demand for modern piped water supply services and put pressure on government to ensure that better services are provided. The challenge for water supply managers serving this first group of households is to raise the financing necessary to pay for the capital-intensive investments needed to expand system capacity and improve water quality and service reliability (Whittington and others 2009a). An understanding of how the quantity of water used by households is affected by tariff structures and other factors is needed to help guide public pricing policies, i.e., to design tariff structures that will both raise funds for financing system improvements and better balance the economic value of water to households with the rising costs of supply.

The second large group of households live in the expanding slums of cities through the developing world and typically have incomes of less than US$150 per month. Many of these households currently lack in-house piped connections and the income to obtain them. In densely crowded slums there are often large positive externalities associated with improved sanitation. Because improved sanitation is crucial for public health, improvements in water supply must compete with sanitation investments for the limited public subsidies. Here the challenge is to design tariffs and subsidies so that the basic needs of all households can be met. At the same time, the incomes of many of these households are also growing, and water planners should not design service options and tariffs that trap these slum households for long periods with intermediate water and sanitation services. For this second group, water planners need a better understanding of both (a) the factors that determine households' water source choice decisions, and (b) the quantity of water used, so that piped services can be offered to the minority of households that can afford them, and other households can be served by cheaper, more basic levels of service.

The third large group of households live in the rural areas of subSaharan Africa and South Asia on less than US$1 per person per day. For the majority of these households, in-house piped water and sanitation services are prohibitively expensive and will remain out of reach for the foreseeable future. The design of rural water supply projects and programs to reach this third group of households has a long history of failure (Therkildsen 1988). Hundreds of millions of dollars have been spent by donors on projects that households do not want and that are subsequently abandoned. Regardless of the type of technology utilized by donors, systems were not repaired and fell into disuse. Cost recovery was minimal and revenues were often insufficient to pay for even basic operation and maintenance, much less capital costs. Communities did not have a sense of ownership in their water projects, and households were not satisfied with the type of services that donors and national governments provided.

Over the past two decades a global consensus has gradually emerged among national governments and donors about what has been learned from this failure and how to best design rural water supply programs to serve households in such communities (Whittington and others, 2009b). Most sector professionals would now agree that a well-designed rural water supply program should …

(1) involve households in the choice of both technology (service level) and institutional and governance arrangements;

(2) give women a larger role in decision-making;

(3) require households to pay all of the operation and maintenance costs of providing water services and at least some of the capital costs;

(4) transfer ownership of the facilities to the community; and

(5) involve households in the design of cost recovery systems and tariffs to be charged.

The role of central government (perhaps assisted by donors) is to decide …

(1) the eligibility rules (i.e., which communities are eligible to participate in the program);

(2) the feasible technological options to offer to communities;

(3) the cost-sharing rules (how much will government pay; how much will communities pay);

(4) the protocol for transferring ownership of facilities to the communities;

(5) the central government's program financing (grants vs. loans); and

(6) how best to provide communities with information about the program.

In order for governments and donors to make informed decisions about the design of these program rules for rural water supply programs, they need better information in particular about household source choice decisions, i.e., the factors that determine whether or not households will decide to use the public taps and community handpumps that are the typical service options provided by rural water supply programs. For this third group of households, the interconnection between sanitation and water investments is less critical than for households living in urban slums. In rural areas, the negative externalities associated with poor sanitation often can be more effectively addressed by behavioral change than by infrastructure investments.

We acknowledge that there is considerable heterogeneity among households in each of these three groups. Nevertheless, we believe this simple typology is helpful because it illustrates that the information on household water demand behavior that is needed for policy decisions is somewhat different for the three groups. For households with piped connections living in the non-slum parts of medium and large cities, water planners need to know how household water use from piped connections responds to changes in tariffs, given that some households may rely on multiple water sources. For poorer households living in slum areas, information on how households with piped connections respond to changes in tariffs is still important, but household source choice decisions themselves assume greater policy relevance because the decision by households to connect to the piped distribution system cannot be taken for granted. Finally, for poor households in rural areas that cannot afford a connection to a piped distribution system, water planners primarily need information about the determinants of the household source choice decisions, not the quantity of water used.

## Estimation of Household Water Demand Functions in Industrialized Countries

### *Literature*

The estimation of household water demand functions in developed countries has been the focus of many empirical papers, starting with the work of Gottlieb (1963) and Howe and Linaweaver (1967). Studies have been made in a large number of countries, including Australia (Grafton and Ward 2008), Canada (Kulshreshtha 1996), Denmark (Hansen 1996), France (Nauges and Thomas 2000), Spain (Martínez-Espiñeira 2002), Sweden (Höglund 1999), and especially the United States (Foster and Beattie 1979; Agthe and Billings 1980;

Chicoine and others 1986; Nieswiadomy and Molina 1989; Hewitt and Hanemann 1995; Pint 1999; Renwick and Green 2000). For comprehensive reviews of this literature see Espey and others (1997), Hanemann (1998), Arbués-Gracia and others (2003), and Dalhuisen and others (2003).

*Modeling Strategies*

In almost all studies performed in industrialized countries, the residential water demand function is specified as a single equation linking (tap) water use (the dependent variable) to water price and a vector of demand shifters (household socioeconomic characteristics, housing features, climatologic variables, etc.) to control for heterogeneity of preferences and other variables affecting water demand.[2] A popular functional form is the double-log, which yields direct estimates of elasticities but constrains the elasticity to be constant. There are few discussions on the choice of functional form, except by Griffin and Chang (1991), who advocate more flexible forms such as the generalized Cobb-Douglas, and Gaudin and others (2001), who discuss the trade-off between simplicity and parsimony of parameters.

This single-equation modeling strategy implicitly assumes that there is no substitute available for water.[3] Water quality and the reliability of the water supply service are generally not included in the single-equation model as controls because there is little variation in terms of service quality across households on the same distribution system. The focus instead has been on the estimation of price elasticity and the measurement of the impact of socioeconomic characteristics (mainly income) on the quantity of water used.

The main methodological issues relate to the choice of marginal or average price and to price endogeneity when households face a nonlinear pricing scheme (e.g., increasing or decreasing block pricing tariff structures). Although economic theory suggests the use of marginal price (the price of the last cubic meter), average price (computed as total bill divided by total consumption) has often been preferred. Authors who use average price argue that households are rarely well informed about the tariff structure used by their local water utility and are thus more likely to react to adjustments in average price than in marginal price. Estimation of the residential water demand function when the pricing scheme is nonlinear has been the focus of numerous articles, including Agthe and others 1986; Deller and others 1986; Nieswiadomy and Molina 1989; Hewitt and Hanemann 1995; Olmstead and others 2007.

*Data*

In studies of household water demand functions in industrialized countries, data for the model estimation typically come from water utility records. An important advantage of relying on water utility records is that panel data on each household's water use are usually available. A disadvantage is that water utilities typically maintain little socioeconomic or demographic information on the households they serve. There is also little variation in potentially important covariates, such as the tariff structure itself and water quality and reliability.

*Results*

Most studies find that household water demand is both price- and income-inelastic. Espey and others (1997) report an average own price elasticity of –0.51 from industrialized countries. Income elasticity has often been estimated in the range [0.1–0.4] (see Arbués-Gracia and others 2003). Other household characteristics (size and composition), housing characteristics (principal versus secondary residence; size of the lawn or garden, if any; stock of water-using appliances), and weather data are commonly acknowledged as determinants of water use in industrialized countries.

**Estimation of Household Water Demand Functions in LDCs: Modeling Strategies**

Analysis of demand for water in LDCs is complicated by abundant evidence that, contrary to what is observed in most developed countries, households in LDCs in all three groups described above have access to and may use more than one of several types of water sources, such as in-house tap connections, public or private wells, public or (someone else's) private taps, water vendors or resellers, tank trucks, water provided by neighbors, rainwater collection, or water collected from rivers, streams, or lakes. The choice set as well as the conditions of access can vary significantly across households. In the formal parts of large cities, piped networks are typically common, but many people may not be connected, for a variety of reasons, and even those that are connected may use a variety of other water sources. In urban slums residents sometimes have access to a connection to a piped network but often exploit a wide variety of water sources.[4] In poorer rural areas, piped distribution networks with private connections are the exception.

Three basic approaches to estimating household water demand functions in LDCs can be seen in the literature: (1) estimation of (unconditional) demand for water coming from one particular source, (2) discrete analysis of source choice, and (3) a combination of the source choice model and a model of water use conditional upon source choice. We now describe these three approaches in turn.

(1) When households rely on a unique source or when water comes primarily from one source, a demand equation for water from that particular source can be estimated from data on the subsample of households using that source. For example, Rizaiza (1991) estimates separately water demand equations for households with a private connection and for households supplied with tankers in the four major cities (with populations between 700,000 and 4 million inhabitants) of the western region of Saudi Arabia (namely, Jeddah, Makkah, Madinah, and Taif). Crane (1994) specifies separate demand equations for a sample of

households living in Jakarta (population around 8 million inhabitants), Indonesia, that were supplied by water vendors and for households relying on public taps (hydrants). David and Inocencio (1998) use data from Metro Manila (population around 11 million inhabitants), Philippines, to estimate separate demand equations for households supplied by water vendors and for households with a private connection. Rietveld and others (2000) and Basani and others (2008) estimate the water demand function for households with a piped connection respectively in Salatiga (a medium-sized city of about 150,000 inhabitants in Central Java, Indonesia) and in seven provincial towns in Cambodia (all between 400,000 and 1 million inhabitants).

(2) In some cases (Crane 1994; David and Inocencio 1998) dummy variables are introduced in single demand equations to control for possible use of additional sources. The estimation of (single) source-specific demand equations provides insight on the sensitivity of water use to the price of water from that particular source. However, this approach does not allow the analyst to measure cross-price elasticities in the case of households that combine water from different sources. A system of water demand equations is a better specification in this case, because it allows the analyst to identify substitutability and complementarity relationships between sources (Cheesman and others 2008; Nauges and van den Berg, 2009).

(3) Several papers have studied household choice of water source, either as a primary focus (Mu and others 1990; Madanat and Humplick 1993; Hindman Persson 2002; Briand and others, in press) or in combination with estimation of conditional water demand models (Larson and others 2006; Nauges and Strand 2007; Basani and others 2008; Cheesman and others 2008; Nauges and van den Berg, 2009). Most of these studies were conducted in urban areas, very often in medium or large cities. Authors generally agree that source attributes (e.g., price, distance to the source, quality, and reliability) and household characteristics (income, education, size, and composition) should both enter the source choice model.

Whereas source attributes account for heterogeneity in water from different sources, household characteristics account for differences in personal taste, opportunity cost of time, and perception of health benefits from improved water.[5]

The most frequent specifications for source choice models are the probit model and the multinomial logit (MNL) model. The probit model has been used when the household choice being modeled is whether or not to acquire a private connection (Larson and others 2006; Basani and others 2008; Nauges and van den Berg, 2009). The MNL model has proved useful for describing either the primary source of water chosen by households (Mu and others 1990; Nauges and Strand 2007) or the water source that is chosen for a specific use such as drinking, bathing, or cooking (Madanat and Humplick 1993; Hindman Persson 2002).[6] The MNL model considers choices between exclusive alternatives and relies on the assumption of independence from irrelevant alternatives (IIA). But for modeling household choice of water sources so as to allow for a combination of sources, the multivariate probit or nested logit models should be the preferred alternative. In the multivariate probit setting, households are assumed to make several decisions, each between two alternatives. Briand and others (in press), in a study of households living in eleven formal but poor districts in Dakar (population around 1 million inhabitants), Senegal, estimated a bivariate probit model to describe household decisions to rely on a private connection and/or public standpipes. The nested logit specification can be seen as a two- (or more) level choice problem (for more details on these models see Greene 2003, ch. 21; for recent approaches that may be useful in the present context see Bhat 2005).[7]

Models describing household choice of water source have recently been combined with conditional models of water demand. The simultaneity between choice of water source and choice of quantity was first acknowledged by Whittington and others (1987), who argued that a complete set of water demand relationships should include models of both water source choice and the quantity of water demanded. If both factors are not taken into account, the simultaneity in both decisions could lead to biased estimates of the demand parameters. In particular, if some unobserved variables affect both the choice of water source(s) and the quantity of water used, estimated parameters could suffer from selection bias (Heckman 1979).

This issue has been discussed by several authors, and a two-step Heckman procedure for correcting selection bias has been applied by, among others, Larson and others (2006) on data from Fianarantsoa, Madagascar (population around 100,000 inhabitants), Nauges and Strand (2007) on data from Central American cities (namely Santa Ana, Sonsonate and San Miguel in El Salvador – population between 65,000 and 200,000 inhabitants-, and Tegucigalpa in Honduras, with a population of about 900,000 inhabitants), Basani and others (2008) on data from seven provincial towns in Cambodia, and Cheesman and others (2008) on data from Buon Ma Thuot (population around 135,000 inhabitants), in the Central Highlands of Viet Nam. Selectivity correction terms are computed from estimation of the discrete choice models described above and added linearly to the demand equations. Statistical significance of these correction terms indicates presence of selectivity bias.[8]

These estimates of the household water demand function have never been used to derive welfare measures, except by Cheesman and others (2008), who derive the effects of quantity restrictions on the surpluses of Vietnamese households.[9] They find that consumer surplus losses from reduced total monthly household municipal water supplies are more pronounced among households that use only municipal water than among households that combine municipal water with well water. This is as expected, because the former group of households has a more inelastic own-price demand and a lack of substitution opportunities.

Welfare analysis following changes in the conditions of water supply for households in LDCs remains a difficult question, in particular when piped water is charged according to a block-pricing scheme and when households that are currently without a connection become able to connect to the piped network. In cases where block pricing is used, consistent estimation of water demand and calculation of the change in consumption following a change in price become computationally challenging (for details, see Olmstead and others 2007). The problem is that it is difficult for the researcher to assess demand for piped water among households that do not yet have a connection to the piped network. The assumption that households as yet without a piped connection will behave, after being connected, the same as households that already are connected, is likely to be too strong in most cases: there is evidence that a household's own characteristics drive both choice of access to specific water sources and the quantity of water used.

The determinants of how total water consumption is allocated among different uses (drinking, cooking, bathing, etc.) is a question that has not yet been studied, so far as we know. This question is likely to be more relevant for LDCs, because water from different sources may be used for different purposes.

**Estimation of Household Water Demand Functions in LDCs: Data Issues**

Analysts attempting to estimate household water demand functions in developing countries face at least four difficult challenges when assembling data. First, households that are connected to piped water networks may nevertheless have unmetered connections: thus no household-level data on the quantity of water used is available from the water utility. In such situations households themselves usually have little idea how much water they use, and direct interviews with households will be of no use in determining any exact or approximate quantity. In such a situation the main options open to the analyst are to install meters (which may change behavior), to monitor (directly watch) household use of water over some interval of time, or to ask the household to keep a detailed water-use diary.

Second, even when households have metered connections, the meter readings are often unreliable. Many piped water systems in developing countries do not provide 24-hour service. When water service in a piped distribution system is intermittent, the water pressure fluctuates. Meters typically will not provide accurate readings because air intermittently enters the pipes, such that the meter may register water as passing through when in fact it is only just air. Also, because water prices are so low in many places, and because corruption is common (Davis 2003), water utilities have little incentive to keep meters in good working order; nor are they replaced on a timely basis. The end result is that in many cases no one knows how much water a household is using—not the utility, not the household, and certainly not the researcher.

Third, when an analyst wants to model source choice decisions for households that have multiple potential sources of water, the source choice model requires data not only on the water sources chosen but also on the sources *not* chosen. For example, a household's decision to purchase water from a vendor will depend not only on the price of water that the vendor charges but also on how far household members would have to walk to fetch water from, say, a well. The analyst would need to know the distance to the well even if the household bought all of its water from a vendor. But standardized household surveys that include questions about a household's water source generally ask the respondent only about the sources the household uses, not the attributes of the sources not chosen. Thus household water demand source choice and discrete–continuous models almost always require specially designed household surveys, even when utility records are available. Even the specially designed household surveys may need to be supplemented with additional data collection activities, because households may not be able to provide quantitative information on some attribute of the sources not chosen (e.g., distance from the dwelling to the source).

Fourth, because information on the quantity of water used is often not available (even from a utility) or of poor quality, researchers have typically relied on cross-sectional surveys of households in the community under study. It is possible to use cross-sectional data in regression models to determine associations between the source chosen (and the quantity of water used) and covariates such as household income, housing type, education levels of household members, and the collection costs of water. It is often difficult, however, confidently to ascribe a causal relationship of the independent variables (the covariates) to the dependent variables (source chosen, quantity of water used) on the basis of analysis of cross-sectional data. Many of the independent variables are arguably endogenous, and good instruments for these are rarely available. For variation in key independent variables over time intervals, time series data are generally required.

Nevertheless, most researchers seeking to estimate household water demand functions in developing countries have used data from cross-sectional household surveys. Occasional attempts have been made to escape the cross-sectional dilemma. For example, Cheesman and others (2008) built an “artificial panel” data set by combining revealed and stated preference data. Diakite and others (2009) use utility data for 156 small towns (all above 3,000 inhabitants) in Côte d’Ivoire over the years 1998–2002.

In addition to these four data problems, researchers encounter challenges associated with measuring specific variables within the model specifications. We discuss some of these below.

*Water Price*

When data are obtained from one-time household surveys conducted in a single city or village, there may be little or even no cross-sectional variation in policy-relevant variables such as connection costs, tariff, and levels of service. In fact, Larson and others (2006) exclude the price of water altogether from their analysis of water demand in Fianarantsoa, Madagascar, because all surveyed households had the same price schedule. One may attempt to overcome this problem by combining revealed and stated preference data, that is, by asking respondents how much water they would use at different (hypothetical) prices (Acharya and Barbier 2002; Cheesman and others 2008). But respondents simply may not know how much water they would use, if the prices for water proposed by the researcher are outside their experience.

For water from nonpiped sources, contingencies vary across places and across sources. Water may be distributed free of charge, or perhaps it is charged at a fixed price per liter. If the surveyed households obtain water from various nontap sources, some cross-sectional variation will likely be observed in the data. Because data on price (and consumption) for households relying on nonpiped sources are usually based on self-reported information (households are usually asked to report the number of buckets that they collect every day), there is room for substantial error in measurement.

*Costs of Water Collection*

Even if water is available from a source away from home free of charge, its collection involves time to go to the source, to wait at the source (queuing), and time to haul the water back home. One may choose to convert collection time into collection costs using an assumed value of time. However, the value of time may differ widely across households depending on who is responsible for collecting water, and even within a specific household over time of day or day of week. In localities lacking formal labor markets or with high unemployment, estimating an average value of time for a study population is largely guesswork. Many analysts thus do not attempt to convert the time cost of water collection into a pecuniary collection cost. For example, Larson and others (2006) consider round-trip walking time to water source and waiting time at the source. David and Inocencio (1998), on a sample from Metro Manila in the Philippines, use distance from source in meters as an explanatory variable in their demand model. Strand and Walker (2005) consider hauling time per unit of water consumed.

Whittington and others (1990b) are among the only authors to provide some empirical evidence about the pecuniary cost of collecting water from nontap sources. Using data from Ukunda, a small market town in Kenya, they develop two approaches, based on discrete choice theory, for estimating the value of time spent collecting water. Their results indicate that the value of time for households relying on nontap sources (kiosks, vendors, or open wells in the village) was at least 50% of the market wage rate and likely to approach the market wage rate for unskilled labor for some households.[10] But this small study for a single community in Kenya cannot be easily generalized to other locations. Nauges and Strand (2007), on household data from Santa Ana, Sonsonate and San Miguel in El Salvador, and Tegucigalpa in Honduras, have conducted the only study where hauling time is translated into a corresponding pecuniary time cost. They use the average hourly wage in the individual household as the shadow cost of time but acknowledge that even this approximation may overestimate actual costs if the hauling is performed by a child. Mu and others (1990) note that in places where queuing time varies significantly over the course of the day, collection time could be determined endogeneously.

*Quality of Water Service*

Because water quality and reliability may vary from one source to another, such variables should be included in household water demand functions for LDCs (as well as in models describing source choice). These include opinion variables about the taste, smell, and color of the water (at all available sources) and hours of water availability and potential pressure problems (for piped water). These data are typically provided by households themselves and may be subject to misreporting. Variables measuring household opinion (or perception) about water quality should also be used with caution, because they may introduce endogeneity into the demand model. For example, households that suffered from water-related diseases in the past may be more inclined than other, healthy households to believe that water is unsafe and may therefore exhibit different behavior regarding water use (Nauges and van den Berg 2006). Also, quality perceptions may be correlated with income and education, implying collinearity issues (Whitehead 2006). To avoid such biases, one could develop an average of opinion (on water quality) for households living in the same neighbourhood, or relying on the same water source, if the average could be computed without considering the opinion of the individual household under consideration (Briand and others, in press).

*Households' Socioeconomic Characteristics*

Household surveys often gather a large amount of information on household socioeconomic and demographic characteristics such as size and composition (by sex and age) of the household, education level and occupation of each member, and earnings, as well as data on household living conditions (structural materials, conditions of access to various services such as electricity, schooling, doctors, etc.). Income is one important variable in the study of water demand that may be difficult to gather in some places. Whittington and others (1990a) used several variables as income (or wealth) proxies, including the construction of the respondent's house (whether the house was painted, whether the roof was straw or tin, whether the floor of the house was dirt or concrete). Basani and others (2008) use household expenditures as a proxy for income, arguing that in surveys households are more likely to understate their incomes than to overstate their expenditures. Another possible proxy approach would be to state wealth via a linear index of asset ownership indicators, using principal-components analysis to derive weights (Filmer and Pritchett 2001).

**Household Water Demand in LDCs: Results**

The studies reviewed in this article have used data from various regions in the world—Central America (El Salvador, Guatemala, Honduras, Nicaragua, Panama, Venezuela), Africa (Kenya, Madagascar), and Asia (Cambodia, Indonesia, the Philippines, Saudi Arabia, Sri Lanka, Vietnam)—and cover a 20-year time span (the earliest survey dates back to 1985; the most recent was conducted in 2006). Tables 1 and 2 summarize, respectively, the main characteristics of studies that model water source choice and water demand, including author(s) of the research, number of households surveyed, study areas, time periods, types of water access available to surveyed households, econometric approach used for model estimation, and main estimation results. With the exception of the research conducted in Ukunda, Kenya, these studies were conducted in medium to large sized cities in LDCs.

*Water Consumption*

The case studies described in discussion throughout this article illustrate the heterogeneity of conditions for access to water across LDCs. Average water use by households with piped connections varies across places: 72 liters per capita per day (lpcd) in a group of seven provincial towns in Cambodia (Basani and others 2008), 88 lpcd in Fianarantsoa, Madagascar (Larson and others 2006), 120 lpcd in Buon Ma Thuot, Vietnam (Cheesman and others 2008), 130 lpcd in Salatiga city, Indonesia (Rietveld and others 2000) and 135 lpcd in urban areas of medium cities from three districts in Southwest Sri Lanka, namely Gampaha, Kalutara and Galle (Nauges and van den Berg, 2009).[11]

Households without a piped connection have lower water consumption in general, with important differences depending on the source on which they rely. Households with a private well usually have a higher consumption level than households relying on public sources. In Santa Ana, Sonsonate and San Miguel (El Salvador) and Tegucigalpa (Honduras), nonconnected households relying on public taps outside the home consume on average 25 lpcd whereas households relying on a private well consume on average 110 lpcd (Nauges and Strand 2007). In Jakarta (Indonesia) nonconnected households that buy water from resellers purchase on average 27 lpcd whereas households that buy water from vendors purchase 15 lpcd on average (Crane 1994).

*Water Price*

Despite heterogeneity in places and time periods studied, authors seem to agree on the inelasticity of water demand in LDCs, with most estimates for households with a private connection in the range of –0.3 to –0.6. Espey and others (1997) report an average own-price elasticity of –0.51 from industrialized countries, suggesting that own-price elasticity for households in developed countries and for those in LDCs is in the same range. Only two studies from LDCs find evidence of an elastic water demand: David and Inocencio (1998) use data from Metro Manila, Philippines, to estimate price elasticity for vended water at –2.1, and Rietveld and others (2000) use data from Jakarta, Indonesia, to estimate price elasticity for piped water at –1.2. Interestingly, Rietveld and others (2000) are the only authors to use the discrete–continuous model first proposed by Burtless and Hausman (1978) and first used for estimating household water demand by Hewitt and Hanemann (1995) in a study in Texas that yielded a price elasticity of –1.6, a figure above (in absolute value) most elasticities that had been estimated in developed countries.[12] In our opinion, the price elasticity estimated by David and Inocencio (1998) should be regarded with some caution, as alternative estimation techniques used on the same data (by the same authors) seem to provide very different price elasticities.

Nauges and van den Berg (2009) on data from three districts in Southwest Sri Lanka (Gampaha, Kalutara and Galle) and Cheesman and others (2008) on data from Buon Ma Thuot, Vietnam, estimate systems of water demand for households with private connections that also consume water from nonpiped sources. Both studies show that piped water and nonpiped water are used as substitutes and that households that rely solely on piped water are less sensitive to price changes than connected households that complement their piped water consumption with water from a private well.[13]

*Costs of Water Collection*

Collection time and distance to the source are found to be significant drivers of household choice of water source(s) (Mu and others 1990, using data from Ukunda, Kenya; Hindman Persson 2002, using data from metropolitan Cebu, Philippines; Briand and others, in press, using data from Dakar, Senegal) and to have a significant negative effect on the quantity of water collected from nontap sources (Mu and others 1990; Strand and Walker 2005; Larson and others 2006; Nauges and Strand 2007; Nauges and van den Berg, 2009). With data from Santa Ana, Sonsonate and San Miguel (El Salvador) and Tegucigalpa (Honduras), Nauges and Strand (2007) estimate elasticity to price and hauling cost to be in the range of –0.4 to –0.7.

*Quality of Water Service*

Choice of water source is found to be driven by piped water pressure level (Madanat and Humplick 1993) and by opinions about taste and reliability of water (Briand and others, in press; Nauges and van den Berg, 2009). If service from a piped connection is available for longer hours, water use by connected households increases (Nauges and van den Berg, 2009). However, the magnitude of the effect is found to be quite small: an extra hour of piped water availability would increase per capita consumption of households in Sri Lanka (districts of Gampaha, Kalutara and Galle) by 2% on average. Variables measuring household opinion about water quality are not found to be significant in household water demand functions in general.

In response to deficiencies in the water supply system, households may invest in coping strategies; that is, they may incur fixed costs in the form of investments in alternate supply sources and/or storage facilities (Pattanayak and others 2005). For example, a household may buy a storage tank in order to mitigate problems with reliability and pressure that may be associated with private house connections, or, if the household relies on well water, pumping equipment may be purchased.

A demand equation that controls for household use of a water storage tank or for tank capacity is featured in analyses by Crane (1994), Cheesman and others (2008), and Nauges and van den Berg (2009). Crane (1994) notes that use of a storage tank (and its capacity) could be endogenously determined in the demand model, as the investment decision regarding the tank (and its capacity) was certainly codetermined with the expected need for water. Endogeneity may not be present if the investment decision was made a long time before the actual (observed) water purchase. Using data for urban households from three districts in Southwest Sri Lanka (Gampaha, Kalutara and Galle), Nauges and van den Berg (2009) estimate that a storage tank in the house increases per capita (piped) consumption by 13% on average.

*Household Socioeconomic Characteristics*

Income (or expenditure) and education level (or the ability of head of household to read and write) have been found to be positively associated with household choice of improved water source (Madanat and Humplick 1993; Hindman Persson 2002; Briand and others, in press; Larson and others 2006; Nauges and Strand 2007; Basani and others 2008; Nauges and van den Berg, 2009). Mu and others (1990) and Briand and others (in press), using data from Ukunda, Kenya, and Dakar, Senegal, respectively, find evidence that household composition affects choice of water source. In Ukunda (Kenya), households with more women were less likely to purchase from vendors (and more likely to rely on water from wells and kiosks), presumably because more people are available in the household unit to carry water. In Dakar (Senegal), the probability that households used water from the piped system increased if head of household was a widow.

In studies estimating water demand, income elasticity (or expenditure elasticity) is found to be quite low, most often in the range 0.1 to 0.3. Household size is found to be significant in most cases. When the dependent variable is total household consumption, larger households are found to have larger water use. When the dependent variable is per capita consumption, scale effects are confirmed: per capita consumption decreases with the number of members in the household. Using data from Buon Ma Thuot, Vietnam, Cheesman and others (2008) found that doubling the number of permanent residents in the household increased household consumption from a piped network by approximately 50%.

**Concluding Remarks**

Our review of the emerging literature on household water demand functions in LDCs suggests that estimates of own price elasticity for water from private connections is in the range of –0.3 to –0.6 and that income elasticity is typically in the range of 0.1-0.3, both close to what is usually reported for industrialized countries. These findings have three important implications for water utility managers in LDCs. First, in medium and large cities with significant numbers of middle-income households, tariff increases probably can be used to increase revenues in order to raise some of the funds needed to finance system improvements and expansion. Second, although demand for water from private connections is inelastic, tariff increases will induce a reduction in the quantity of water demanded, and thus can be an important component of a water demand management program. Third, although the estimates of income elasticities are relatively small, in countries that are experiencing high rates of economic growth, water utility managers should anticipate powerful upward pressures on household water demand from increases in income. In locations where the marginal costs of water supply are raising, this reinforces the need to use tariff increases to better manage demand.

In contrast, the literature on household water source choice, especially in rural areas, is still in its infancy, and in our judgment the empirical findings are much less robust. The explanatory variables suggested by economic theory are, in fact, associated with household water source choices and are often statistically significant and have the expected signs. However, the magnitude of the parameter estimates seems to us quite location specific, and the policy implications less clear. We speculate that further research will show that in many circumstances household water source choice decisions will be quite sensitive to changes in prices of water from different sources and household incomes, in contrast to the findings from the literature on the quantity of water demanded by households with private connections living in medium to large cities. Programs designed to recover operation and maintenance costs, and some capital costs, thus may have significant effects on households' use of new water infrastructure, especially in rural areas, a conclusion reached by Kremer and Miguel (2007) for households in their study villages in rural Kenya. This suggests that better demand information on household source choice decisions is needed in many rural areas and urban slums to design subsidies and tariffs. This should be a high-priority research area.

Because so many people in developing countries lack improved water supply services, public health officials and many donors have little patience with economists' arguments about optimal allocation of investment funds and the need to subject water supply projects to cost-benefit analysis. It seems obvious that people are dying from diseases that could be largely eliminated by improved water and sanitation services. Improvements are thus needed urgently, and if subsidies are necessary, so be it. If the water policy discourse is framed in this manner, information about how customers respond to different service options and pricing schemes is not likely to be a high priority to decision makers.

Because many water utilities in LDCs have few incentives to undertake careful economic appraisals of investment projects, or to price delivered water to their customers in order to recover costs or meet an economic efficiency objective, water utility managers have not placed a high priority on obtaining better information on household water demand behaviour. Few water utilities in LDCs are financially self-sufficient; most receive capital and in many cases even operating subsidies from higher level governments and donors. Their focus is naturally on the providers of subsidies.

However, there are reasons this situation may soon change, and the findings from the literature on household water demand functions may become more policy-relevant. At the macro level economic growth and the increased hydrologic variability brought about by climate change are placing new pressures on the water sources used by all three groups of households described in this paper. As variability in the raw water supplies increases, providing reliable supply to households becomes more expensive. Governments throughout the world are also facing increasing challenges over allocation of water resources among different users. Both climate change and intersectoral competition for water make demand management increasingly important, and thus reinforce the need for a better understanding of household demand for improved water services in different circumstances.

There have, however, been exceptions to policymakers' general neglect of this literature on household demand for improved water services. First, there is an increasing recognition that existing water and sanitation tariff structures are not achieving their stated equity objectives, and that subsidies to the water sector are not reaching the poor (Komives and others 2005; Boland and Whittington 2000). This has led to a new willingness on the part of some utilities to experiment with different water tariff structures, which leads naturally to a consideration of how consumers will respond to changing prices and incomes.

Second, there is a growing appreciation among water utility managers that water pricing decisions regarding public taps and private connections need to be coordinated. This has been due in part to the findings from the literature reviewed in this paper. In some cases demand studies have suggested that water from public taps can be provided free because this policy will not affect demand for water from private connections (World Bank Water Demand Research Team 1990). In other locations this is not the case, and information on household demand is needed to avoid the serious policy mistakes that can arise from pursuing independent, uncoordinated pricing strategies (Whittington and others 1998).

Third, in many cities in LDCs, water utility managers are increasingly recognizing the competition they face from water vendors (Whittington and others 1991). Utility managers that are losing sales and market share to water vendors may wonder what attributes of the services of water vendors households prefer, and what it would take to get households to connect to the water utility's distribution system. This financial interest in increased revenues leads utility managers to the water demand literature reviewed in this paper.

Fourth, numerous international organizations, including the Gates Foundation, have recently focused their attention on the need to improve the quality of drinking water provided to households in developing countries. There has been renewed interest in point-of-use technologies to treat water in the home. This has also raised questions about household demand for improved drinking water quality; how much households value different attributes of service, and the costs and benefits of different point-of-use technologies (Whittington and others 2009a). Again, these policy issues are generating new interest in the water demand literature in LDCs.

Two important questions about household water demand behavior in developing countries remain unanswered, or simply cannot be addressed with existing data. First, existing data do not permit measurement of how household water use would respond to the establishment of dual networks (one for drinking and cooking water, the other for uses that do not require high-quality water). Analyses of household allocation of water among various uses could be a first step.

Second, welfare analysis following changes in the conditions of water supply for households in LDCs remains a difficult question, in particular when piped water is charged according to a block-pricing scheme and when scenarios involve the connection of currently nonconnected households to the piped network.

[1] Most analyses made in industrialized countries have been based on aggregate consumption data provided by water utilities (usually from billing records).

[2] When working on data from industrialized countries, authors commonly assume that the water demand function derives from the maximization of a household's utility subject to a budget constraint, under the assumption that water is a homogeneous good that has no direct substitute or complement. In LDCs, the underlying theoretical model is described slightly differently: water demand is usually assumed to derive from a model in which the household is considered a joint production and consumption unit (for a description of such demand models see Berhman and Deolalikar 1998). In such models, the demand for water can be regarded as a derived input demand in the production of household health (because water consumption may have health consequences). As a consequence, health enters a household's utility, along with consumption goods, leisure time, and other household's characteristics such as education. This preference function is then maximized subject to a time–income constraint and a set of production functions. For related discussions see Acharya and Barbier (2002) and Larson and others (2006).

[3] The only exception is Hansen (1996), who considers water and energy prices in the demand function for water.

[4] That some households utilize more than one source may indicate that their use of a particular convenient source is rationed (implying that additional water must be taken from an alternative source), or that it is relatively cheap to take some water but not all from a particular source (e.g., the household may have limited capacity to haul cheap water from a given source and prefers to obtain the rest more expensively from another source); or that waters from different sources are used for different purposes (drinking, bathing, cleaning, etc.).

[5] Kremer and others (2007) use data on household water source choices (in a travel cost model) to estimate a revealed preference measure of household valuation of the water quality gains generated by spring protection in rural Kenya.

[6] Hindman Persson (2002) estimates a probit model but points out that a nested conditional logit model would be better suited. Madanat and Humplick (1993) estimate a two-level sequential choice model to distinguish between the decision to obtain a private connection and the choice of nontap sources.

[7] Analysis of source choice may be complicated insofar as the entire set of sources available to the household is not known to the econometrician. Hindman Persson (2002) assumes that each household's location within the city determines its set of available sources.

[8] For computation of correction terms when a probit is used in the first estimation stage, see Heckman (1979); for computation when an MNL is used, see Lee (1983) and Dubin and McFadden (1984).

[9] Cheesman and others (2008) employed a combination of revealed and stated preference techniques. These authors asked households how much water they would use if the price of water changed. They find that the own price elasticity for household water use is extremely low (-0.059). This estimate needs to be interpreted carefully in the context of the local water situation in their study area in Vietnam. The local water utility was only charging about US$0.15 per cubic meter. It is thus not surprising that households would say that they would not change the amount of water they would use if the price doubled because the volumetric rate still would be very cheap. It seems to us implausible that the own price elasticity is -0.059 throughout the range of hypothetical prices offered to respondents. Such extremely inelastic demand might be plausible at much lower levels of water use per capita. But per capita water use in the study area was relatively high. A typical Vietnamese household in the sample without a private well was using about 16 cubic meters per month – roughly equivalent to household water use in many European cities.

To see how odd these results are, consider the estimates of gross surplus losses. A typical Vietnamese household in the sample was paying a water bill of about US$2.25. Chessman's welfare calculations suggest that this household would be willing to pay about $8 to avoid having a supply restriction imposed of 3.5 cubic meters per month (from 16 to 12.5 cubic meters per month). In other words, the household would be indifferent between paying US$2.25 for 12.5 cubic meters per month, or paying $10.25 for 16 cubic meters per month. We doubt that these Vietnamese households actually place such a high value on modest supply restrictions given that their income is quite modest.

[10] These estimates were higher than the ones recommended by the Inter-American Development Bank (IADB) at the time: for the IADB, time savings should be valued at 50% of the market wage rate for unskilled labor (Whittington and others 1990b).

[11] The European average is 150 lpcd; see European Environment Agency at <http://themes.eea.eu.int/Specific_media/water/indicators/WQ02e%2C003.1001/index_html>

[12] Meta-analyses conducted on data from industrialized countries provide mixed evidence on the effect of functional form and estimation method on the level of price elasticities. Espey and others (1997), in a meta-analysis of 124 price elasticity estimates generated between 1963 and 1993, find no significant effect neither of the functional form (linear versus log-linear) nor of the estimation method (OLS versus others). Dalhuisen and others (2003), who extended Espey and others database up to the year 2000, found that discrete/continuous choice (DCC) models (see Hewitt and Hanemann 1995, Rietveld and others 2000) produced price elasticities that were significantly higher (in absolute value) than elasticities obtained using other approaches. However, this finding is weakened by the recent study of Olmstead and others (2007): using a DCC model on household data from 11 urban areas in the United States and Canada, they find a moderate price elasticity of -0.33. The number of studies using the DCC model is too small to be able to draw any definite conclusion on the link between functional form, estimation method and price elasticity.

[13] Nauges and van den Berg (2009) use the approach introduced by Shonkwiler and Yen (1999) to control for censoring of observations in a system of simultaneous equations. This is because not all piped households complement their tap water consumption with water collected from a private well.

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## Appendix – Data Collection Issues

Our overview in this paper of empirical issues has shown that careful analysis of household water demand in LDCs requires gathering a great deal of information from each household surveyed. The prudent researcher will bear in mind the following seven issues when designing a household survey on water use:

1. Surveys should ideally be made in more than a single city or village, in order to acquire data with cross-sectional variation regarding conditions of water services, in particular price, connection fee, and quality and reliability of services.
2. In most cases, only data on sources that are actually used by the surveyed household are available. Ideally, one should identify the complete set of sources available to the household (whether used or not) and gather information on time to walk from home to any off-site source(s) used or not used, the waiting (queuing) time at the source(s), price of the water, possible rationing or constraints (opening hours, limited availability), and quality of the water from each source (whether used or not). These considerations are a prerequisite for consistent estimation of household choice of water sources.
3. For households relying on nonpiped sources, information on the persons in charge of collecting the water should be gathered, so that appropriate wage rates can be applied for estimating the shadow price of hauling.
4. At the time of the survey, interviewers should test each household’s knowledge about its consumption and water expenditure during the last piped water billing period, and household members’ knowledge of the pricing scheme.
5. It may be important to control for demand seasonality, because demand (in total and for water by source) may vary over the course of a year.

6. For planning, it may also be important to control for number of permanent and nonpermanent household members.
7. To determine whether water infrastructure (storage tank, pumping equipment) is endogenous, that is, whether current household water usage might be linked to acquisition of new infrastructure, installation dates can be recorded to serve as a measure of how recently these were purchased.

**Table 1.** Household choice of water source: an overview

| **Reference** | **Household *N*, study region, period** | **Type of water access** | **Decision variable** | **Choice set** | **Model specification and estimation method** | **Significant explanatory variables** |
|---|---|---|---|---|---|---|
| Mu and others (1990) | 69 hh from Ukunda (Kenya), 1986 | - kiosks<br>- water vendors<br>- open wells<br>- hand pumps | Choice of primary water source | Assumed to be exogenous: all hh face the same choice set | Multinomial Logit model (MNL)<br><br>Maximum Likelihood (ML) approach | - collection time<br>- price of water<br>- number of women in the hh |
| Madanat and Humplick (1993) | 900 hh from Faisalabad (Pakistan), 1992 | - private connection<br>- public piped water<br>- motor/hand pumps<br>- water vendors<br>- wells/ponds/canals | Choice of usage-specific water source (for drinking, bathing, washing, etc.) | Not all the alternatives are available to all hh<br><br>Focus here on hh that can connect to the water system | Two-level decision model<br><br>Sequential ML estimation | - education level<br>- presence of a storage tank<br>- piped water pressure level |
| Hindman Persson (2002) | 769 hh in Cebu (Philippines) | - piped in house<br>- pump in house or yard<br>- rainwater<br>- public pump or piped water<br>- open well<br>- surface water<br>- purchased water | Choice of drinking water source | Suggests that the set of available sources is determined by choice of living areas | Suggests using a nested conditional logit but uses a MNL instead because of too few observations<br><br>ML approach | - annual labor income<br>- walking time to source |
| Larson and others (2006) | 547 hh from Fianarantsoa (Madagascar), 2000 | - private connection<br>- collecting hh | Decision to get or not to get a private connection | Assumed to be exogenous: all hh face the same choice set | Probit model<br><br>ML approach | - education level<br>- income |

**Table 1 (cont'd).** Household choice of water source: an overview

| Reference | Household *N*, study region, period | Type of water access | Decision variable | Choice set | Model specification and estimation method | Significant explanatory variables and estimated elasticities |
|---|---|---|---|---|---|---|
| Nauges and Strand (2007) | 553 nontap hh from 3 cities in El Salvador and 826 nontap hh from Tegucigalpa (Honduras), 1995–1997 | - private or public well<br>- someone else's private tap<br>- public tap<br>- trucks<br>- rivers/lakes | Choice of primary nonpiped water source | Assumed to be exogenous: all hh face the same choice set | MNL model<br><br>ML approach | - income<br>- size of the property<br>- access to electricity<br>- hh size<br>- interviewee reads and writes |
| Basani and others (2008) | 782 hh from 7 provincial towns in Cambodia | - private connection<br>- rivers/streams<br>- tanks<br>- wells<br>- vendors | Decision to get or not to get a private connection | Assumed to be exogenous: all hh face the same choice set | Probit model<br><br>ML approach | - connection fee<br>- expenditure (as a proxy for income)<br>- ethnic group |
| Briand and others (in press) | 301 hh from Dakar (Senegal), 2005 | - private connection<br>- public standposts | Decision to use a private connection and/or a public standpost | Assumed to be exogenous: all hh face the same choice set | Bivariate probit<br><br>ML approach | - distance to standpost<br>- hh's head is a widow<br>- interviewee reads and writes<br>- average opinion on piped water reliability<br>- average opinion about service at the standpost<br>- renter/owner status |
| Nauges and van den Berg (2009) | 1,800 hh from Sri Lanka, 2003 | - private connection<br>- public taps<br>- public and private wells<br>- neighbors<br>- surface water | Decision to get or not to get a private connection | Assumed to be exogenous: all hh face the same choice set | Probit model<br><br>ML approach | - income<br>- education of hh's head<br>- access to other sources<br>- taste and reliability of water from other sources |

**Table 2.** Estimation of water demand in developing countries: an overview

| **Reference** | **Households *N*, study region, period** | **Type of water access** | **Demand model specification and estimation method** | **Dependent variable** | **Significant explanatory variables and estimated elasticities** |
|---|---|---|---|---|---|
| Mu and others (1990) | 69 hh from Ukunda (Kenya), 1986 | - kiosks<br>- water vendors<br>- open wells<br>- hand pumps | Single demand equation with dummy to control for type of water access<br><br>OLS method | Water used per capita per day | - collection time (–)<br>- income (+) |
| Rizaiza (1991) | 563 hh from four major cities in Saudi Arabia, 1985 | - private connection<br>- tankers | Separate demand equations for hh with a private connection and hh supplied with tankers<br><br>OLS method | Annual water demand per household | - price elasticity ranging from –0.40 (for tankers water) to -0.78 (for piped water)<br>- family size (+)<br>- income elasticity in the range 0.09–0.20<br>- average temperature (+)<br>- dummy for garden in the property (+) |
| Crane (1994) | 291 hh from Jakarta (Indonesia), 1991 | - piped system<br>- water vendors<br>- public hydrants<br>- hh resellers<br>- neighbors with in-house connection | Separate demand equations for hh supplied by vendors and hh relying on hydrants + dummy to control for use of extra sources<br><br>OLS method | Hh monthly water use | - price elasticity ranging from –0.48 (for vended water) to –0.60 (for hydrant water)<br>- time per purchase (– for vended water)<br>- capacity of water reservoir (+ for vended water) |
| David and Inocencio (1998) | 506 hh from Manila (Philippines), 1995 | - piped system<br>- tubewell pumps<br>- water vendors | Separate demand equations for hh supplied by vendors and for hh with a private connection<br><br>2SLS estimation for correction of price endogeneity | Hh monthly water use | - price elasticity estimated at –2.1 for vended water<br>- income elasticity estimated at 0.3 for vended water |
| Rietveld and others (2000) | 951 hh from Salatiga (Indonesia), 1994 | - private connection<br>- neighbors<br>- community water terminal<br>- wells<br>- rivers | Single demand equation for water from a private connection<br><br>Discrete–continuous approach of Burtless and Hausman (1978); ML method | Hh monthly water use | - price elasticity: –1.2<br>- income elasticity: 0.05<br>- household size (+)<br>- use of extra sources (–) |

**Table 2 (cont'd).** Estimation of water demand in developing countries: an overview

| Reference | Household *N*, study region , period | Type of water access | Estimation method | Dependent variable | Significant explanatory variables and estimated elasticities |
|---|---|---|---|---|---|
| Strand and Walker (2005) | About 3,700 hh from 17 cities in Central America, surveys made 1995–1998 | - private connection<br>- public taps<br>- trucks<br>- wells<br>- rivers/lakes | Separate demand equations for hh with a private connection and for non-tap hh<br><br>2SLS estimation for tap water equation and OLS estimation for nontap water equation | Hh monthly water use | - price elasticity in the range –0.3 (for hh with a private connection) to –0.1 (for nontap hh)<br>- income elasticity less than 0.1<br>- household size (+)<br>- hauling time (– for nontap water) |
| Larson and others (2006) | 547 hh from Fianarantsoa (Madagascar), 2000 | - private connection<br>- public taps<br>- wells<br>- natural sources | Separate demand equations for collecting hh and hh with private connections<br><br>Two-step Heckman approach to control for use of a private connection | Hh monthly water use | - household size (+)<br>- roundtrip collection time (– for collecting hh) |
| Nauges and Strand (2007) | 553 nontap hh from 3 cities in El Salvador and 826 nontap hh from Tegucigalpa (Honduras), 1995–1997 | - private or public well<br>- someone else's private tap<br>- public tap<br>- trucks<br>- rivers/lakes | Single demand equation for nontap water, allowing for elasticities to water cost varying with type of water access<br><br>Two-step Heckman approach to control for choice of primary nontap source | Water use per capita per month | - total water cost (price + hauling cost) elasticity in the range –0.4 to –0.7<br>- income elasticity in the range 0.2 to 0.3<br>- household size (–) |
| Basani and others (2008) | 782 hh from 7 provincial towns in Cambodia | - private connection<br>- rivers/streams<br>- tanks<br>- wells<br>- vendors | Single demand equation for connected hh<br><br>Two-step Heckman approach to control for use of a private connection | Hh monthly water use | - price elasticity in the range -0.5 to -0.4 (connected hh)<br>- expenditure elasticity in the range: 0.2 to 0.7 (connected hh) |

**Table 2 (cont'd).** Estimation of water demand in developing countries: an overview

| Reference | Household *N*, study region, period | Type of water access | Estimation method | Dependent variable | Significant explanatory variables and estimated elasticities |
|---|---|---|---|---|---|
| Cheesman and others (2008) | 166 hh from Buon Ma Thuot (Vietnam), 2006 | - private connection<br>- private wells<br>- vendors | Separate estimation for hh using a private connection only (single equation) and hh combining water from a private connection and well water (system)<br><br>Two-step Heckman approach to control for use of well water | Hh monthly water use | - price elasticity for piped water estimated at -0.06 for hh using a private connection only and at –0.53 for hh using a private connection and well water<br>- income elasticity: 0.14<br>- household size (+)<br>- use of a storage tank (+) |
| Nauges and van den Berg (2009) | 1,800 hh from Sri Lanka, 2003 | - private connection<br>- public taps<br>- public and private wells<br>- neighbors<br>- surface water | Separate systems of demand equations for piped and nonpiped hh<br><br>Two-step Heckman approach to control for use of a private connection; Tobit model for censored observations | Water use per capita per month (for piped hh) or per day (for nonpiped hh) | - price elasticity in the range –0.15 to –0.37 for piped hh<br>- collection time (– for non-piped water)<br>- income elasticity: 0.14 for piped hh and 0.20 for non-piped hh<br>- use of a storage tank (+)<br>- hours of piped water availability (+ for piped water)<br>- household size (– for non-piped hh ) |