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Household water's economic value in Buon Ma Thuot, Viet Nam

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EXECUTIVE SUMMARY

Short run economic values of untreated water at source (raw water) to urban households in Buon Ma Thuot, Dak Lak are estimated in this research report. The short run values households in Dak Lak place on raw water are directly comparable with short run raw water values in alternative uses, such as irrigated dry season agriculture. To manage water resources in Dak Lak consistent with the requirements of Viet Nam's Law on Water Resources, estimates of the relative values derived from water in alternative allocation are required. The estimates in this research also provide an important practical planning information basis for Rural and Urban Water Supply and Sanitation projects currently being undertaken in Dak Lak, especially in the areas of sustainable pricing and demand forecasting.

The research findings are based on a survey dataset of 291 urban and peri-urban households. Respondent households are found to be heavily dependent on municipal connections for household water supply; view both municipal and well water quality favourably but with some seasonal and income based variation; predominantly use municipal and well water for household activities and use bottled water for drinking in a minority of households; have in-house water storage capacity to hedge against supply outages; have automated well water extraction with motorized pumps; undertake limited water preparation activities (with the exception of drinking water preparation) and have limited labour involvement in collecting and preparing water for household activities. For households consuming water from the municipal supply system only, average per capita daily consumption is approximately 125 litres. Households using both municipal and private well water consume approximately 65 litres per capita per day from the municipal system on average and supplement this with approximately 75 litres per capita per day from the household's well.

Household water demand and value estimates are obtained for households using municipal water only and both municipal and well water. A price elasticity of -.06 is estimated for households using municipal water only. Own price elasticities of -.51, -.32 and cross price elasticities of .44 and .31 are estimated for households using both municipal and well water respectively. Household water supply and storage infrastructure and socio-economic characteristics are found to shift household demand for water. Based on the demand elasticity estimates the households' economic value of raw water are estimated. To obtain an estimate of the economic value of raw water to households, six supply shortage scenarios are evaluated,

ranging from one to six cubic meter decrements in total monthly supply to the average household. For households using the municipal system as their only water source, the economic value for raw water is estimated to lie between VND1,500 for a one cubic meter supply decrement and VND350,000 per cubic meter for a six cubic meter supply decrement. The economic value of raw water to households using both municipal water and household well water have lower municipal raw water values, ranging between VND300 for a one cubic meter decrement in total monthly household supply and VND4,500 per cubic meter for a six cubic meter decrement.

CONTENTS

1 INTRODUCTION

Competition for dry season water resources between the agricultural and urban sectors is increasingly evident in the Dak Lak Plateau of Viet Nam. An Urban Water Supply and Sanitation project completed in 2002 has provided reliable, hygienic and pressurized water to the provincial capital Buon Ma Thuot and has seen urban consumption increase dramatically. The municipal water supplied by the project is drawn from springs and deep wells in lower confined aquifers in predominantly coffee and rice producing areas. Water diversions to Buon Ma Thuot for household uses imposes opportunity costs on smallholder irrigators in terms of foregone potential production benefits from irrigated agriculture and increased irrigation pumping costs that result from an induced lowering of the water table in the upper aquifer as a consequence of pumping from the lower aquifer. As Rural Water Supply and Sanitation projects are extended to other regional urban centres in Dak Lak it is likely this system of localized impacts will be replicated.

In order to assess the trade-off between competing uses of water, estimates of the relative values derived from the alternatives are required. However in Dak Lak, little is known about household demand or the value placed on municipal water supplies[1]. In Buon Ma Thuot the fixed tariff charged per cubic meter of water supplied to the household does not reflect the marginal utility gained by the household from using an extra cubic meter of water, nor does it allow estimation of household price elasticity. For planning and valuation purposes an understanding of households' demand responsiveness to price is required. Knowledge of how household demand would shift in response to changes in income or other household factors is also desirable. All municipal supply costs are not recovered under the current municipal pricing system. Understanding household water price elasticity would create a basis for establishing a pricing regime aimed at financial sustainability for the local water supply company. Apart from these issues, many urban and peri-urban households in Buon Ma Thuot also have access to a second water source, normally a household well. Households' ability to obtain water from multiple sources complicates the estimation of household water demand and hence valuation estimates.

[1] Municipal water includes residential, public and other uses.

This research report estimates the economic value of undiverted, untreated household water (raw water) in Buon Ma Thuot, focusing on municipal and private well supply sources. The paper is structured in seven sections. Section 2 provides a background to the research issue. Central concepts underpinning household water demand functions and household water values are introduced in section 3. The econometric models used to estimate household singular demand for municipal water and simultaneous demand for municipal and well water are defined in section 4.2 based on a behavioural household production function model of water demand outlined in section 4.1. The novel survey approach, which elicits both revealed and stated preference data from household respondents is described in detail in section 5. The veracity of the approach is confirmed in section 6.2. The at-site household water demand functions are estimated in section 6.3 and results discussed. Based on the estimated household water demand functions, the economic value of increasing household water supply is evaluated for households consuming municipal water only and households consuming both municipal and well water in section 6.4. Conclusions are made in section 7.

2 BACKGROUND

Buon Ma Thuot, the unofficial provincial capital of Dak Lak, is located in the Central Highlands of Viet Nam. A Water Supply and Sanitation Project co-financed by the Viet Nam Ministry of Construction and the Danish Ministry of Foreign Affairs was completed in March 2002. The system provides potable municipal water to approximately 100,000 people with a purported maximum supply daily production capacity of 49,000 cubic meters. This is equivalent to sufficient capacity for 250,000 people at an average consumption of 200 litters per capita per day. The Buon Ma Thuot Water Supply Company (BMTWSC) operates as an autonomous State agency responsible for the supply system. The BMTWSC charges a fixed rate of VND2,250 per cubic meter for municipal supplies. All households receiving water from the municipal system have a meter. Monthly household water bills are calculated on the basis of metered consumption.

The Buon Ma Thuot Water Supply Company draws water from a system of spring water infiltration galleries and collection wells and deep aquifer drilled production wells located to the east of Buon Ma Thuot. These urban water collection sites were developed or expanded as part of the Water Supply and Sanitation project. The main spring collection systems are located in rice and coffee producing areas in Ea Co Tam, Cu Pul, Ea M'sen, Dat Ly and Cu Pul North and the main production wells are in coffee producing areas in Thang Loi, Hoa Thang and Dat Ly (Carl Bro International a|s, 1998). At project inception it was recognized spring diversions to Buon Ma Thuot would substantially reduce natural flows to local wetland rice systems and larger downstream agricultural areas (Carl Bro International a|s, 1998). Further, it was recognized that the well production system would lower the groundwater table in the lower aquifer, which would induce a lowering of the groundwater tables in the unconfined aquifer and reduce dry season baseflows in rivers and streams downstream of the well fields (Carl Bro International a|s, 1998, Moller, 1997). The physical impacts of sustained diversions to Buon Ma Thuot on the region's local hydrology impose direct opportunity costs on affected farmers in the form of foregone production benefits from irrigated agriculture and increased groundwater pumping costs. To date however, quantitative analysis of the economic impacts of these transfers on the affected parties, both the water gainers and the water losers, has not been undertaken. The evaluation of household demand and value of water outlined in this report estimates the benefits to the water gainers.

Article 4 of Viet Nam's Law on Water Resources (1998) requires that the State and implementing Peoples' Committees manage and exploit water resources in a "rational, economical and efficient manner". Article 20 requires that river basin water planning be based on the "real potential" of the water source and that allocations within a river basin must ensure the principles of "fairness, reasonability, and priority in the quantity and quality of water for living". The rational economic efficiency objective strictly requires that scarce water within a river basin should be allocated to the use that provides the highest marginal net benefit[2]. Allocation rules guided by such an aggregate efficiency objective may conflict with fairness and "reasonability" objectives and a strict priority allocation to "water

[2] The Law on Water Resources does not define the term "efficiency" and it is therefore ambiguous whether efficiency is meant to imply aggregate economic efficiency, neutral economic efficiency or some other efficiency definition. Because aggregate economic efficiency dominates water resource economics and policy, it is assumed the LWR means aggregate economic efficiency wherever the term is used.

for living" however[3]. Given the legislative background and the lack of previous household water valuation work in Dak Lak and Viet Nam more generally, an examination of demand for and the net benefit of water in urban household use can provide practical insights and serve as a part basis for the development of river basin level water allocation rules, water pricing policies and other water related institutions.

The majority of households in Buon Ma Thuot are connected to the municipal supply system. Many households combine water from the municipal supply system with water from other sources including private wells, vendor water and bottled (drinking) water. Not all water source alternatives are available to all people living in Buon Ma Thuot. For example, some households have access to municipal and vendor water but do not have access to well water because no well exists in their area. Little is known about the pattern of household water usage from non-municipal supply sources. Consumers also incur different fixed and variable costs in order to secure and prepare water for different uses. This is in part based on the source they draw from, but also due to household convenience and quality preferences for water in different uses. Understanding the extent to which urban and peri-urban households use alternative water sources and would change their consumption from non-municipal sources in response to changes in the supply attributes of the municipal source is important for urban water planning and the development of a sustainable municipal water pricing structure.

3 DEMAND AND VALUE OF WATER IN HOUSEHOLD USE

3.1 DEMAND AND VALUE OF WATER IN HOUSEHOLD USE: INTRODUCTORY CONCEPTS

Benefits from municipal water supplies can potentially accrue to both municipal water consumers and water suppliers. For the consumer, benefits accrue from using water as either an intermediate or final consumption good less the costs of obtaining the water. For the producer, benefits can be realized from the supply of water. For a municipal supplier, benefits are in the form of revenue from metered water billing less marginal costs of transforming raw water into municipal water and delivering it to households. For a water

[33] Especially when the LWR does not identify the quantity of water that is required "for living".

vendor profits may also be realized. Currently the Buon Ma Thuot Water Supply Company operates at a loss with operating cost shortfalls subsidized by the State. Total producer surpluses from other water supply activities are likely to be limited due to their small scale and a competitive underlying market; as a consequence this paper concentrates on the estimation of the value of the benefits of water to households.

Households receiving municipal water supplies in Buon Ma Thuot are price takers, and the value of water that would be reflected in an equilibrium market is unobserved as a result. Similarly, equilibrium market prices cannot be observed for households using well water because only household specific extraction costs can be observed. Household specific extraction costs may be a poor proxy for the net benefit the household receives from obtaining an additional volumetric unit of water from the source, especially when the marginal cost of obtaining water from a source approximates the average cost, which is likely to be the case in Buon Ma Thuot. Given highly imperfect markets for municipal and well water the only way to measure the benefit of an additional volumetric unit of water to the household is through the construction of household water demand functions (Gibbons, 1986).

Generally, following Gibbons (1986) and Young (2005), a household's water demand function defines the household's willingness to pay for an increment of water supply. Household willingness to pay for the increment is evaluated by the area under the household's water demand curve over the supply increment (S + AC in Figure 1). The value of this area defines the household's at-site value of water and is the gross benefit of supplying the water to the consumer. At-site implies both the supply costs and opportunity costs of benefits foregone from using the water in a next best alternative are not accounted for. In order to obtain a more readily comparable value for the supply increment, the cost of treating and delivering water to the household and opportunity costs must be subtracted (AC). Subtracting both treatment and delivery and the opportunity cost of the water in its next best use yields an estimate of the change in social welfare brought about by the allocation. Subtracting only the treatment and delivery costs from the gross benefit estimate yields the economic value of the raw water (RWV) (Young, 2005). When municipal water is priced to recover the full costs of supply, the RWV is also the consumer surplus. Dividing the raw water value by the change in supply volume yields an estimate of the economic value of raw water per unit volume (Young, 2005: 259). Where transmission losses are significant the raw water value should be adjusted to account for these losses. Value of raw water per unit volume estimates are directly comparable to other per unit volume estimates of raw water for alternative uses such as irrigated agriculture and in-situ allocation. These basic concepts are developed further in section four of the research report.

3.2 ESTIMATING AT-SITE HOUSEHOLD WATER DEMAND FUNCTIONS: PREVIOUS APPROACHES

The starting point for imputing the economic value of raw water to the household is the household's at-site water demand function. The household's water demand function can be generally expressed in the abstract as a function of the price of water from the consumption source, the price of water from alternative sources, income and other environmental and household specific characteristics. In the absence of equilibrium market prices water demand functions need to be estimated outside of a market. There is no general consensus in the literature on the best methodological approach to analyzing household water demand (Arbues, et al., 2003, Young, 2005). The dominant approach in the applied literature is to estimate continuous demand functions based on either revealed or stated preference data using econometric techniques (see Arbues, et al., 2003 or , Dalhuisen, et al., 2003 for meta-analyses of revealed preference approaches and , Thomas and Syme, 1988 for the only known application of a stated preference approach to estimate direct and cross price elasticities, also Young, 2005). The majority of the econometric demand estimation literature focuses on estimating direct price elasticity for municipal supplies using aggregate data (see Nauges and van den Bergh, 2006: 2 for a summary of demand eslasticities in developing countries, Saleth and Dinar, 1997: 17).

The strong separability condition imposed by single demand function estimates prevents the evaluation of cross-price elasticity parameters when the household consumes from more than one water source. To the extent that demand for water is linked to household decisions about preferences for water consumption by source, estimation of single source continuous demand will be incomplete and may result in biased welfare estimates (Barnard and Hensher, 1992). For planning purposes and to estimate household welfare from water consumption, consumption preferences by all available sources must be evaluated. Simultaneous-equation models provide one approach to estimating these conditional household demand functions. Previous applications of simultaneous equation modelling to estimate household water demand are limited. Acharya and Barbier (2002) pooled revealed and stated preference data to estimate linear household demand functions for (1) households who collected water only (2) households who purchase water from vendors only and (3) households who both collected and purchased water in Northern Nigeria. Separate demand functions for (1) and (2) were estimated using random effects generalized least squares. Joint household demand (3) was estimated using seemingly unrelated regression. Nauges and van den Bergh (2006) used revealed preference data to estimate single and simultaneous demand models for households in Sri Lanka with and without municipal water connections. A two-step Heckman approach was employed. In the first step, a discrete choice model is estimated to control for potential selectivity bias in household characteristics as determinants of the household's municipal connection status. In the second stage, single and simultaneous equations were used to evaluate demand for households drawing from single and multiple sources using ordinary least squares estimates and seemingly unrelated regression respectively.

3.3 ESTIMATING AT-SITE HOUSEHOLD WATER DEAMAND FUNCTIONS FROM STATED PREFERENCES

Stated preference techniques can be employed to estimate household demand for water when water markets do not exist or are highly imperfect and when weak substitute or complementary relationships do not exist or are poorly defined between the imperfectly marketed water and some other market good (Freeman, 2003). Broadly, stated preference techniques construct hypothetical markets in an attempt to simulate household preferences for resource allocation given a well defined set of constructed market conditions. The hypothetical nature of the stated preference elicitation technique may give rise to response bias for various well-documented reasons (Bateman, et al., 2002). The contingent behaviour approach is one stated preference technique for simulating behavioural responses to hypothetical situations. The contingent behaviour approach elicits an intended behavioural response contingent on a hypothetical change in the variable under consideration (Hanley, et al., 2003). Pooling revealed and contingent behaviour data has been demonstrated to improve the efficiency of demand model estimates (Englin and Cameron, 1996).

Acharya and Barbier (2002) and Thomas and Syme (1988) both employed contingent behaviour techniques to evaluate household level behavioural and technical responses to changes in water prices. Acharya and Barbier (2002) presented households with incremental cost schedules for obtaining water from two sources and had respondents indicate the quantities they would consume by source given the relative prices. This approach assumes that households could reliably estimate total water demand given a schedule of relative prices without resorting to a detailed analysis of their water consumption activities. Thomas and Syme's (1988) approach avoided reliance on this assumption, deriving household demand estimates based on a detailed household water consumption activity analysis. Under this approach, households first kept a diary of actual water consumption for their main water consuming activities. The household water consumption activity budget was then employed to define how the household would change their consumption by activity given hypothetical changes in the volumetric supply price of municipal water supplies.

4 SPECIFICATION AND ESTIMATION TECHNIQUE

4.1 CONCEPTUAL MODEL OF AT-SITE HOUSEHOLD WATER DEMAND

Household water demand is a function of some underlying household decision making process that takes into account preferences for household water uses and household constraints on acquiring water for use (Razafindralambo, et al., 2003). For households that use labor to collect and prepare water for use, a non-separable conceptual model is needed to estimate at-site household water demands because the household must choose between allocating scarce labor between water collection and preparation and income generating activities. For households that do not incur real labor resource costs in water collection and preparation a separable model is sufficient (Razafindralambo, et al., 2003). The conceptual model employed here assumes household water demand is based on a non-separable behavioural model of the household as a joint production and consumption unit (Maler, 1991, Razafindralambo, et al., 2003, Yen, et al., 2002). Households either consume water directly or use it as an input to produce other goods or services. Households seek to maximize utility from consumption and production activities given source alternatives available to them and budget and labor constraints. For a two source model of municipal water (mw) and private household well water (pw) Acharya and Barbier's (2002) household consumption / production model of water demand can generally be expressed as:

$$Q_i = Q_i(\mathbf{A}, p_{mw}, p_{ww}, \mathbf{Z}) \qquad (4.1)$$

where Q_i is the quantity demanded from source i, i = mw is municipal water, i = ww is well water, the vector $\mathbf{A}$ describes separate water quality attributes of the municipal and well water such as pressure, reliability, turbidity, taste etcetera, p_{mw} is the price of the municipal source per cubic meter, p_{ww} the shadow price of well water and $\mathbf{Z}$ is a vector of household specific characteristics including income and labour potential. The optimising household consumes municipal and well water until the marginal utility of consuming the good is equal to the marginal utility of producing and purchasing the good. Depending on household labour and budget constraints and water quality and relative price attributes the household will either (1) consume quantities from both water sources so as to equate marginal net utility of consumption between the sources (2) use municipal water only or (3) use well water only[4]. For households consuming municipal water only the behavioural model reduces to:

$$Q_{mw} = Q_{mw}(\mathbf{A}, p_{mw}, \mathbf{Z}) \qquad (4.2)$$

4.2 ECONOMETRIC SPECIFICATION OF AT-SITE HOUSEHOLD WATER DEMAND

Following the logic of the conceptual household model, separate econometric models of household water demand can be estimated for households with municipal water connections only and households with municipal water connections and access to a private household well. To obtain unbiased estimates of the household demand functions requires that the survey population sub-samples for the municipal water only and municipal water and private well households are random (Nauges and van den Bergh, 2006). It is possible however that there are latent variables that contribute towards determining whether a household has a well or not. Potential sample selection bias is controlled for using Heckman's (1979) two step estimation procedure, outlined in the following section.

4.2.1 DETERMINATION OF HOUSEHOLD WELL STATUS

The choice model characterizes the discrete choice variable (d_i) as 1 if the household has a private well and 0 if they do not. Assuming a normal probability distribution of the error term (u_i), the decision model in probit form is:

$$\Pr(d_i = 1) = \Pr(\mathbf{x}_{1i}\beta_1 \prec u_i) = \Phi(\mathbf{x}_{1i}\beta_1) \tag{4.3}$$

where $\mathbf{x}_{1i}$ is a matrix vector of the explanatory variables of household private well status, β_1 the estimated coefficients and $\Phi(\mathbf{x}_{1i}\beta_1)$ is the cumulative normal distribution. The inverse Mill's ratio is calculated with the estimated parameters from the probit model and included in the household water demand models to control for selection bias (Heckman, 1979). The inverse Mill's ratio is estimated as:

$$M_i = \frac{\phi(x_{1i}\hat{\beta}_1)}{[1-\Phi(x_{1i}\hat{\beta}_1)]} \tag{4.4}$$

where $\phi(.)$ is the standard normal probability density function and $\Phi(.)$ is the cumulative normal distribution.

4.2.2 AT-SITE HOUSEHOLD WATER DEMAND FUNCTIONS

For households using the municipal water supply only, the general household demand function is defined as[6]:

$$Q_{mw} = c_1 + a_1 p_{mw} + a_2\mathbf{A}_{mw} + a_3\mathbf{C}_{mw} + a_4\mathbf{E} + a_5\mathbf{Z} + a_6 M + e_1 \tag{4.5}$$

The conditional demand function for households using water from both municipal and private well sources is defined by:

[4] See Acharya and Barbier, 2002, pp. 417-418

[6] The household index is dropped for simplicity

$$Q_{mw} = c_2 + a_7 p_{mw} + a_8 p_{ww} + a_9 \mathbf{A}_{mw} + a_{10}\mathbf{C}_{mw} + a_{11}\mathbf{A}_{ww} + a_{12}\mathbf{C}_{ww} + a_{13}\mathbf{E} + a_{14}\mathbf{Z} + a_{15}M + e_2 \quad (4.6)$$

$$Q_{ww} = c_3 + b_1 p_{ww} + b_2 p_{mw} + b_3 \mathbf{A}_{mw} + b_4\mathbf{C}_{mw} + b_5\mathbf{A}_{ww} + b_6\mathbf{C}_{ww} + b_7\mathbf{E} + b_8\mathbf{Z} + b_9 M + e_3 \quad (4.7)$$

The variable p_{mw} represents the price of municipal water and p_{ww} defines a shadow price of private well water. $\mathbf{A}_{mw}$ and $\mathbf{A}_{ww}$ are vectors describing water quality attributes of the municipal and well water respectively, whereas the matrix-vectors $\mathbf{C}_{mw}$ and $\mathbf{C}_{ww}$ describe water preparation activities by main classes of consumption (washing, food preparation, drinking etcetera) and are independent of p_{mw} and p_{ww}. The vector $\mathbf{E}$ describes in-house supply augmentation infrastructure, $\mathbf{Z}$ describes household socio-economic characteristics and M is Mill's ratio. The remainder are coefficients to be estimated. These conditional demand functions are implemented using a constant price elasticity model form in section 6 of this paper.

4.3 THE ECONOMIC VALUE OF HOUSEHOLD WATER

The at-source value of an increment in household water supply is found using the point expansion approach (Young, 2005: 256-262). Assuming a constant price elasticity demand function (i.e. double log form) the gross household benefit associated with an incremental change in water supplied is:

$$\mathrm{V} = \left(\frac{\mathrm{P}_1 * \mathrm{Q}_1^{\frac{1}{|\varepsilon|}}}{1 - \frac{1}{|\varepsilon|}} \right) \left(\mathrm{Q}_1^{1-\frac{1}{|\varepsilon|}} - \mathrm{Q}_2^{1-\frac{1}{|\varepsilon|}} \right) \quad (4.8)$$

where P_1 and Q_1 represent the initial price and quantity point, $|\varepsilon|$ is the absolute value of the own price elasticity of demand estimate, and Q_2 is the final quantity point. This expression describes is the entire area under the household demand curve for the supply increment and is therefore measures the increment's gross value at the household site. Assuming no water delivery losses in transmission, water's raw value (consumer surplus) is obtained by subtracting the treatment and transport costs from the total benefit, V::

[7] But not independent of the water quality attributes and potentially household specific characteristics.

$$S = V - [AC*(Q_1 - Q_2)] \quad (4.9)$$

Here, S is the raw water value of the supply increment to the consumer, representing the maximum amount the consumer would be willing to pay for the raw water at source if the full cost of supplying the total volume of water to their household were to be passed on to them. Dividing S by the additional volume of water supplied yields the raw water value per unit volume for the supply increment.

5 APPLICATION

The estimated household water demand schedules in this paper are constructed based on revealed and stated preference data collected from a sample of urban and periurban households in Buon Ma Thuot. The highly imperfect pricing scheme for municipal water in Buon Ma Thuot and the lack of a common shadow price for household well water means stated preference techniques are the only approach capable of obtaining a spectrum of household price quantity observations for estimation of the household water demand functions. This section's objective is to describe the approach employed to elicit the revealed and stated preference household water demand dataset.

Prior to survey administration a series of focus groups were organized in Buon Ma Thuot. These focus groups served to identify households' water concerns and develop a draft questionnaire. The draft questionnaire was pre-tested on approximately 50 households in Buon Ma Thuot. The questionnaire was revised and a decision was taken to focus on the two largest categories of water consuming households in identified during the pre-test – households consuming municipal water only and households consuming municipal water and water from private household wells. Households who were not connected to the municipal supply system as part of the Water Supply and Sanitation program constitute a third major water consuming group in Buon Ma Thuot, but were not surveyed in this study. These households generally rely on private wells for their household water. Enumerators from Ho Chi Minh City University of Economics and Tay Nguyen University administered the survey. The survey sampling strategy was based on a random sampling scheme according to the location of the household.

The final questionnaire consisted of six parts. Sections one and two identified the sources of water available to the respondent household and the sources the household actually used. It also obtained experiential, operating cost and perceptual background data on municipal and private well water. Section three obtained information on household water storage capacity and costs. Section four identified the households' main water source for the six largest water using activities by volume[8]: bathing and washing; meal preparation; drinking; cleaning; laundry and outside / gardening uses. Treatments used to prepare water for each household activity were obtained by source in order to understand their opportunity costs.

Section five was dedicated to revealed and stated preference elicitation scenarios. For households using municipal water only the objective was to evaluate current demand and cost by household water use activity and then use these estimates as a basis for evaluating how household demand for municipal water would shift given hypothetical changes in the municipal water price. For households using both municipal and household well water, the objective was to evaluate current water demand for both sources and costs by household activity and then use these estimates as a basis for evaluating how household demand for both sources would shift given hypothetical changes in the volumetric (shadow) price of one of the sources. The stated preference scenarios thereby employed a contingent behaviour approach, having respondents focus on how their water consumption would change for specific household activities given changes in the price of water.

Households were first assisted by a trained enumerator to estimate their average daily household demand for water from different sources for seven household activities: bathing, meal preparation, drinking, hygiene (washing, cleaning and toiletry), laundry, gardening, and in-home business activities. The enumerator first walked through the respondent's household and identified with the respondents where activities using water occurred. Following initial identification, the enumerator estimated the average amount of water used in each activity on a daily basis with the respondents. Because different household members are broadly responsible for different water using activities, both the male and female household heads were asked to participate in this process where possible. Having both

[8] Defined by the pre-test

household heads respond to the enumerator has the additional advantage of reducing the potential for strategic behaviour because the respondents essentially audit each other's responses and there is open discussion on points of difference (Thomas and Syme, 1988). The household members estimated their daily water usage based on observation and demonstration of water usage. In the case where activities did not occur on a daily basis, such as for some outdoor activities, weekly usage figures were estimated.

After household water usages for the main household activities were estimated the enumerator extrapolated monthly household water usage and water costs by source. The costs of municipal water supplies were extrapolated based on the existing fixed tariff charged by the Buon Ma Thuot Water Supply Company of VND2,250 per cubic meter. For households using household well water, the monthly water budget was estimated assuming a volumetric shadow price based on an assumed opportunity costs of a representative well using household. While it would have been conceptually possible (and preferable) to estimate a well water shadow price per cubic meter for each respondent household, in practice this proved to be prohibitively time consuming and was perceived to be likely to result in biased shadow price estimates due to the complexity of calculating the shadow price on the spot. The survey focus groups, pre-test and discussions with local authorities suggested households were relatively homogenous in the way they acquired, stored and used well water and daily volumes consumed (a hypothesis broadly supported in section 6). For the stated preference analysis, a shadow price of VND450 per cubic meter was employed to extrapolate the monthly household well water budget.

The household's revealed preference water activity budget for all sources was employed to evaluate direct and, where substitution sources were available, cross price changes in household water demand in response to hypothetical changes in the cost of water from different sources. For households using municipal water, the price change was a hypothetical increase or decrease in the fixed tariff charged by the Buon Ma Thuot Water Supply Company per cubic meter. For household well water an increase or decrease in the average shadow price of groundwater extraction was specified without directly specifying the basis for passing on the increased or decreased price[9].

Each household was presented with two contingent behaviour scenarios for each water source used. In the first scenario households were presented with a supply price higher than the current (shadow) price. In the second scenario households were presented with price lower than the current price. For households using two water sources (municipal water and household well water) the scenarios evaluated hypothetical price changes in one source at a time only, keeping the price of the other source at its current level. In total, municipal supply households were presented with eight hypothetical prices ranging between 0.22 and 11.11 times the fixed volumetric tariff currently charged by the BMTWSC[10]. Six hypothetical prices were used to evaluate households' contingent water consumption behaviour given changes in the shadow price of household well water, ranging between 0.22 and 6.67 times the assumed shadow price of VND450 / m^3 [11]. These prices were determined on the basis of pre-testing.

In the municipal water supply scenarios the enumerator first told respondents the new municipal water price and then calculated the household's new water bill based on the household water usage activity budget completed in the previous section. This approach allowed households to see the total monthly water cost of each household activity, given the new hypothetical price, as well as the new total household bill. Respondents were then prompted whether they would change their household water use given the hypothetical municipal water price. If respondents answered no, the enumerator recorded the reason why the household would not change. If respondents indicated they would change their household water usage level, the enumerator worked with the household to determine how the household would change their water usage consumption by water using activity.

[9] While this approach may have sacrificed some incentive compatibility, attempting to frame the cost increase in terms of increased electricity prices implicated potential cross-price effects for other household activities and the household budget. Attempting to frame the cost in some other terms, such as an increase in annual pump maintenance costs, led respondents to become confused and distracted from the task at hand. In practice we found households simply accepted the volumetric cost increase for well water. This is probably because the private well contingent behavior scenarios were presented after the municipal water scenarios, and by this time respondents were familiar with the 'rules of the game'.

[10] Current price in bold (VND/m^3): 500/1000/**2250**/2500/5000/7500/10000/15000/25000

[11] Current price in bold (VND/m^3): 100/**450**/1000/1500/2000/2500/3000

Changes in water consumption by household activity could be driven by either behavioural, technical or structural modifications (Thomas and Syme, 1988). In practice however the vast majority of household respondents simply focused on short-term behavioural adjustments, either changing water consumption quantities, adopting water recycling (such as using gray water for watering gardens) or switching between water sources.

After respondents had revised their household water using activities given the new hypothetical price, the enumerator worked out their new household water bill. If the respondents were satisfied with the new bill the enumerator proceeded to the next scenario. If the household was not satisfied, the enumerator worked with the respondents to revise the water usage pattern. This procedure was repeated until an acceptable household water bill was obtained. For the well water scenarios the procedural logic was the same.

While the revealed preference / contingent behaviour approach employed to estimate household water demand functions was procedurally intensive and time consuming, it has several advantages over alternative approaches. Simply asking a household how they would change total water volumes consumed by source given changes in volumetric sourcing costs, as has been done in previous studies, may not produce reliable household demand estimates because it pre-supposes that households know how much water they use by household activity and the extent to which changing behaviors, introducing new technology or undertaking structural alterations would impact total household water consumption. Pre-testing suggested, in Buon Ma Thuot at least, that households could not perform this calculus without the enumerator's assistance and using an empirically based 'walk-through' estimation procedure. The second advantage of the approach is that it can be used to identify the components of household water use that are more price elastic than others. This, in itself, is an important piece of water planning information. Finally, because the approach gives respondents the opportunity to revise their water allocations based on the hypothetical household water bill, it is consistent with the Discovered Preference Hypothesis (Plott, 1996), which suggests stable and valid preferences are gained through practice and repetition.

The survey data are unique as a micro-level cross-sectional dataset. Because all households receiving municipal water from the Buon Ma Thuot Water Supply are on metered connections, actual consumption data from this source have a relatively high degree of accuracy and can be used to validate household reports of water consumption by activity for households using municipal water.

6 RESULTS

6.1 DESCRIPTIVE STATISTICS

Descriptive analysis shows respondent households are characterized by a dependency on municipal water; view both municipal and well water quality favourably but with some seasonal and income based variation; predominantly use municipal and well water for household activities; have sizable in-house water storage infrastructure primarily to stock against municipal supply outages; have mainly automated their well water extraction; excepting drinking water do not devote much effort to preparing water for use; have limited labour involvement in collecting and preparing water for household activities and do not know the municipal water tariff structure (Table 1).

Approximately 43 percent of respondents reported that their municipal connection is the only water source available to their household. Roughly 25, 20 and 25 percent of the surveyed households reported having a private well, purchasing bottled water or having water from another unspecified source available to them. In terms of water sources actually being used by households as opposed to being available for use, around 55 percent of all respondents reported only using metered municipal water for household activities. With an average household size of 4.7 persons, these households consume approximately 120 litres of municipal water per capita per day. Households augmenting municipal water supplies with a second source – either a private well, bottled water and other sources accounted for 11, 13 and 11 percent of respondents respectively. This implies approximately 95 percent of respondent households draw water from no more than two sources, including approximately 80 percent of respondent households using either municipal water exclusively or combining municipal and well water. They also indicate that roughly half of the households with an available supply alternative to municipal water select not to use the alternative for any household activities. Households augmenting municipal water with household well water only or with well water and water from another source have lower daily per capita consumption from the municipal system compared to households relying on the municipal system only at 70 litres per capita per day.

During both wet and dry seasons municipal water quality was regarded as good or better by over 60 percent of the surveyed population. Less than three percent of the surveyed population viewed wet or dry season water as poor quality. There is some evidence that perceived municipal water quality drops during the wet season. Similar quality perceptions hold for households using private wells. During the dry season well water is reported as being of good quality or better by 70 percent of using households. This drops to 55 percent during the wet season with reports of poor well water quality increasing to 25 percent. This is consistent with local reports of increased well water turbidity and smell during the rainy season. For houses using both municipal and well water these results indicate high degrees of potential substitutability.

Almost nine out of ten respondent households reported having some form of in-house water storage infrastructure and about two-thirds of these respondents installed this infrastructure before the BMT water supply project was completed. With approximately 80 percent of respondent households only storing municipal water it is clear that households predominantly use water storage to hedge against rolling dry season supply shortages that have historically plagued BMT. Before the Urban Water Supply and Sanitation project's completion these outages were mainly caused by unreliable and ineffective water supply infrastructure, but more recently the outages have been caused by the extreme dry season droughts. The most popular form of water storage is in-household cement storage tanks, which were installed in almost seven out of every ten households surveyed. These storage tanks hold an average capacity of approximately 2.5 cubic meters, which is sufficient to supply 4.5 days water for an average-sized household consuming 120 litres per capita per day. Households using water from wells have largely automated the process with approximately 85 percent using motorized pumps with an average pump capacity of 1.2 HP. Even though households using both well and municipal water recorded similar perceived quality levels for municipal and well water, less than 10 percent of households with water storage blend municipal and well water in the same storage facility.

With the exception of drinking water, the respondent households did not undertake any water treatment for the main household activities: bathing, meal preparation, cleaning, laundry and gardening. Households with in-house water storage generally let impurities sink in the storage tank prior to use. This treatment requires no labour input because it occurs automatically as part of the storage process. In contrast, and consistent with expectations, water preparation for drinking occurred in almost all respondent households. Of the 291 respondent households, 230 used municipal water, 48 purchased bottled water and the remainder obtained it from other sources. Households purchasing bottled water used it exclusively for drinking; these households did not treat this water further. Of the 230 households using municipal water for drinking, only five percent did not treat the water before consumption. Ninety five percent of all surveyed households using municipal water for drinking boiled the water before consumption and 16 percent subsequently filtering that boiled water.

The water consumption profiles of surveyed households provide a basis for specifying the contingent water demand functions estimated in the following section. Because labour is not an important input for the majority of respondent households in the collection, storage and treatment of either municipal or household well water, a separable model of household demand is specified. In section 6.3 separate at-site water demand models are estimated for households consuming water from the municipal source only and households consuming both municipal and household well water. Prior to demand estimation, the ability of respondent households to accurately predict their monthly household municipal water consumption is evaluated in section 6.2.

6.2 HOUSEHOLDS' ABILITY TO PREDICT CONSUMPTION

The veracity of the estimated household water demand functions hinges, in part, on the assumption that households can estimate their per capita daily water use for with reasonable accuracy. This assumption is evaluated by comparing households' estimated monthly municipal water use against their metered water usage using pair-wise correlations[12]. Support is found for the household activity analysis as a basis for determining total monthly municipal water consumption for households using municipal water only and households using municipal water and private wells. On the truncated dataset[13] pair-wise correlations of total monthly household municipal water consumption estimated by the household water activity analysis and metered total monthly consumption are significant at the one percent level for both models (municipal only pair-wise r=0.70, n=108) (municipal and well pair-wise r= 0.86, n=56). The accuracy of respondent households' estimates of municipal water consumption supposes accuracy in the household water consumption estimates for well water. Based on this assumption, current average monthly well water consumption is estimated at 11 cubic meters per month, equivalent to just over 75 litters per capita per day for the average household. Total combined household consumption from the household well and the municipal supply is approximately 19 cubic meters, about 140 litters per capita per day. These results suggest that at current prices, households with wells choose to consume the majority of their water from their well. The results also imply households with access to both municipal and well water consume approximately 15 litters more water per capita per day than households with municipal connections only.

6.3 AT-SITE HOUSEHOLD WATER DEMAND FUNCTION ESTIMATION RESULTS[14]

The panel data is created by pooling data on households' actual behaviour given the water tariff and assumed well opportunity cost and their contingent behaviours following

[12] Based primarily on households' metered municipal water bill for July 2006. Not all households had metered water bills for July. A clustered metered water consumption variable was created by appending households' June or May water bill where their July bill was unavailable. Only 7 households did not report at least one bill and these households were dropped from the analysis because there was no way of demonstrating these households could accurately predict total monthly consumption.

[13] In the sub-sample of households consuming water from both sources, one outlier household had metered household consumption above 30 cubic meters per month. This household predicted their water consumption poorly. As an influential outlier the household's inclusion would bias estimates and an upper truncation at 30 cubic meters per month was adopted as a result. The analysis was also constrained to households reporting some non-zero municipal water consumption because there is no basis for determining whether these households could accurately estimate their monthly demand. The truncated dataset was 56/70 of the full sample. Similarly, for the analysis of households consuming municipal water only the dataset was truncated at the lower bound to include households with non-zero metered consumption. Note also that metered consumption was recorded by enumerators rounded to the nearest whole number, which may introduce some estimation error.

[14] Categorization of respondent households as either municipal households or municipal and well households is required for the demand function analysis. In reality, all households have access to water sources other than the municipal source. For example, all households have the option of collecting rainwater or purchasing bottled water. The decision rule applied to categorize households is that the sources "available" to the household are the ones they indicate are either currently being used or would be used in any of the contingent behavior scenarios. For example, if a household only uses municipal water now and in response to all of the contingent behavior scenarios, they are categorized as municipal water only households. If a household uses both municipal water and well water now or indicated they would use both sources in at least one of the contingent behavior scenarios, they were classified as dual source households.

hypothetical changes to either municipal water or well water price. Before proceeding with demand estimation, main effect dummy variables were constructed for the revealed preference scenarios to test whether households' revealed and stated preferences were constructed using the same underlying demand preference structure. The null hypothesis that the dummy coefficients for revealed preferences were not different from zero was confirmed in all cases, leading to the conclusion that the two datasets are derived from the same preference structure.

6.3.1 DETERMINANTS OF HOUSEHOLD WELL STATUS

Maximum-likelihood estimation results for the probit model describing households' well status (have household well=1) are provided in Table 5. The model is significant at the one percent level (Log pseudo-likelihood = -100.40, Wald chi2(5) = 23.04); household income, in-house water storage capacity and having farming or self-employment as the primary household occupation are significant predictors. Increasing household income decreases the probability that a household has a well, which is consistent with observations from the household water consumption profile. As a household's in-house water storage capacity increases so does the likelihood of having a well. Operating a farm increases the incidence of household wells, an unsurprising finding given farms are located primarily in peri-urban areas in Buon Ma Thuot and most farms have wells for crop irrigation. Being self-employed also increases the probability of owning a private well. Separate regressions of farming and self-employment on income show that these are not significant predictors, indicating they are not income proxies. The model provides 70 percent correct predictions. The inverse Mill's ratio is calculated with the estimated parameters from the probit model for inclusion in the water demand models to control for selection bias (Heckman, 1979).

6.3.2 AT-SITE HOUSEHOLD DEMAND FOR MUNICIPAL WATER

A main effect, at-site household water demand function is estimated using random effects GLS for households using municipal water only[15]. The panel dataset consists of 329 observations from 108 households (Table 4). The dependent variable is the log of monthly

[15] Because the panel dataset includes variables with invariant within group values, the random effects model is preferred over both the pooled and fixed-effects model alternatives. A Hausman test was used to test the appropriateness of the random effects model. The test did not reject the null hypothesis that the random effect model was consistent and efficient.

household water consumption in cubic meters. To control for potential selection bias the inverse Mill's ratio derived from the estimation of households' log likelihood of having a private well was initially included as an explanatory variable. Several functional forms were evaluated and only the best fitting model is reported here. The model for at-site household municipal water demand for a household (panel) (*i*) elicitation ('time') (*t*) using municipal water only is defined by:

$$\ln(Q_{mw,i,t}) = c_1 + a_1 \ln(p_{mw,i,t}) + a_2 \ln(hhsize_i) + a_3 D_{store,i} + a_4 \ln(store_i) + w_{i,t} \quad (6.1)$$

ln denotes logarithms to base e; Q_{mw} is the quantity of municipal water consumed by the household per month in cubic meters; p_{mw} is the price of municipal water per cubic meter; $hhsize$ is the number of permanent household residents[16]; D_{store} is a dummy variable equal to zero if the household has in-house water storage and one if they do not; and $store$ is the volume of in-household water storage capacity in cubic meters; and w is a additive composite error term made up of an individual specific error component that is constant across time and an error component that is specific to the particular observation[17]. The model is significant at the one percent level (Wald chi2(4) = 430.4 Prob > chi2 = 0.00, Adj. R^2 = 0.43). The retained model coefficients are significant and are signed consistent with expectations.

Surveyed households demonstrate inelastic demand for municipal water. Own price elasticity is estimated at -0.062, implying that a 20 percent increase in the price of municipal water would result in households reducing monthly consumption by approximately 1.2 percent (in cubic meters) on average over the short run. Given that households using municipal water only already have low per capita daily consumption, the price inelasticity estimate is consistent with expectations. Respondent households are already conservative water users, with the majority of water being used on largely non-

[16] Defined as the number of people living in the household during the past five months.

[17] The composite error term $w_{i,t}$ contains two additive components u_i, the individual level effect and $e_{i,t}$, the disturbance term. To be a consistent estimator the individual level effect must be orthogonal to both the regressors and the disturbance term. Both error distributions are assumed to be normal. See Baum, C. *Introduction to modern econometrics using STATA*. College Station: Stata Press, 2006. or Wooldridge, J. M. *Econometric Analysis of Cross Section and Panel Data*. Cambridge: The MIT Press, 2002.

discretionary activities. Based on these findings, one policy implication is that manipulation of the municipal water price is unlikely to be an effective tool for controlling household water use over the short term, if this is a policy objective, for the majority of households in Buon Ma Thuot that are connected to the municipal system.

Apart from price elasticity effects, household size has a positive effect on total monthly municipal water consumption with a semielasticity of 0.60: for every additional household member total monthly household water consumption increases by approximately 60 percent. Approximately 17 percent of the surveyed households using municipal water exclusively do not have in house water storage. To overcome potential estimation bias arising from coding households with zero storage volume as some arbitrarily small number when transforming the data to logarithm form, the method proposed by Battese (1997) is employed. This approach involves creating a dummy variable (D_{store}) coding households with no in-house water storage equal to one and households with positive storage levels equal to zero and then coding zero level inputs in ln($store$) equal to one. Having in-house water storage increases monthly municipal water consumption by 24 percent compared to households that do not have in-house storage[18]. For the sub-sample of respondent households with in-house water storage infrastructure, total monthly household consumption increases by approximately two percent for every 10 percent increase in total storage capacity, regardless of the storage type. Household income, water quality perceptions, water shortage experience, the highest education level of the household head, main household employment and Mills ratio were not singularly or jointly significant explanatory variables.

6.3.3 SIMULTANEOUS AT-SITE HOUSEHOLD DEMAND FOR MUNICIPAL AND WELL WATER[19]

Separate main effect at-site demand estimates for respondent households using both municipal and well water are estimated on a truncated dataset consisting of 285

[18] Having in-house water storage increases the log of the total monthly household consumption by 0.267 cubic meters. This corresponds to a increase in total monthly household consumption of [exp(0.267)-1] = 24 percent.
[19] Some households using both well and municipal water reported zero level well water consumption in some scenarios. When converting zero consumption to logarithms this presents an impossible number problem given ln(0) is undefined. To overcome this problem, it was assumed households reporting 0 monthly consumption from the well actually consumed 1 cubic meter of

observations[20] [21]. To control for potential selection bias the inverse Mill's ratio derived from the estimation of households' log likelihood of well status is included in both demand estimates. Seemingly unrelated regression is employed to control for error correlation across the demand estimates. The dependent variable in both equations is the log of the total household water consumption per month in cubic meters. The models for at-site household municipal and well water demand for a household (i) are defined by:

$$\ln(Q_{mw,i}) = c_2 + a_7 \ln(p_{mw,i,t}) + a_8 \ln(p_{ww,i,t}) + a_9 \ln(inc_i) + a_{10}\, pcap_i + w_{i,t} \tag{6.2}$$

$$\ln(Q_{ww,i}) = c_3 + b_1 \ln(p_{ww,i,t}) + b_2 \ln(p_{mw,i,t}) + b_3 \ln(hhsize_i) + b_4\, pcap_i + b_5 D_{store,i} + b_6 \ln(store_i) + b_7 D_{farm,i} + b_8 D_{hbus,i} + w_{i,t} \tag{6.3}$$

where Q_{ww} is the total monthly household consumption of well water; p_{ww} is the shadow price of well water per cubic meter; inc is average monthly household income in Vietnamese Dong; $pcap$ is the motorized pump capacity for the household well in HP; D_{farm} is a dummy variable taking the value of one if the household's main employment comes from farming; D_{hbus} is a dummy variable equal to one if the household operates a home based business and zero otherwise and all other variables have been previously defined. The estimated models are significant at the one percent level (municipal demand F= 36.35, p=.000, R-square=0.31; well demand F= 24.97, p=.000, R-square=0.37) (Table 5). In both demand specifications retained model coefficients are generally significant and have signs consistent with expectations. The Breusch-Pagan test of independence rejects the null hypothesis that the residuals from the two demand estimates are independent (chi2(1)= 115.79, Pr = 0.000). This outcome demonstrates that simultaneous estimation of households' demands for municipal and well water is necessary to control for correlation in the error terms and to obtain efficient standard error estimates.

Estimated own price elasticity in both demand models are higher than for households using municipal water only. Own price elasticity for municipal and well water is –0.51 and

well water per month, resulting in ln(1)=0. This works out to about 5 litres of well water per capita per day for a normal household using both sources.

[20] Two households reporting well water consumption in excess of 400 litres per capita per day were excluded from the dataset because these estimates were not considered realistic for the household profiled. The sample included households previously excluded in the pair-wise correlation analysis because they did not provide a water bill to the enumerator. Further, the analysis was constrained to include households that reported having a household well.

[21] The 290 observations are obtained from approximately 60 households.

–0.32 respectively, both significant at the one percent level. Cross price elasticity for municipal and well water are .44 and .31 respectively, also significant at the one percent level. A test of cross equation constraints rejected the null hypothesis of equality for own price elasticities at the five percent level but did not reject the null hypothesis for cross price elasticities. The own and cross price elasticity estimates demonstrate respondent households would readily substitute municipal and well water in response to price changes, and are more responsive to changes in the municipal water price when switching out of municipal water. For example, a 10 percent increase in the volumetric price of municipal water would cause households to reduce monthly household water consumption from the municipal source by five percent, and offset this reduction in part by increasing household consumption from their private well by 4.4 percent. Similarly, in response to a 10 percent increase in the shadow price of well water the household would reduce total monthly well water consumption by approximately 3.2 percent and offset this entirely with increased municipal water consumption. These findings are consistent with observations from the water use profile (section 6.1) that suggest households largely view water from municipal connection and private wells as substitutes for one another in most household activities.

Income elasticity is a significant predictor of household demand for municipal water but not well water. A ten percent increase in monthly household income is approximately commensurate with a 3.5 percent increase in total monthly household water consumption from the municipal source. Combined, these results indicate a preference for increasing municipal water consumption as households become more affluent, holding well water consumption constant. The main policy implication is that increasing household affluence in Buon Ma Thuot will result in greater demand for municipal water and greater total household water demand[22], all other factors constant.

For every one horsepower increase in a households' motorized well pump capacity, monthly household consumption of municipal water is reduced by approximately 28 percent and monthly well water consumption is increased by approximately 62 percent. Because household pump capacity acts as a supply constraint, this finding makes intuitive

[22] Whether the change in total household consumption as a function of income is significant in a statistical sense is not evaluated here.

sense. As pump capacity increases so does the convenience of drawing water from the household well, resulting in higher consumption volumes. As household water storage capacity increases so does monthly well water consumption. The explanation for this outcome mirrors that of pump capacity: having more water available for immediate use in the household storage tank reduces potential for supply constraints and results in higher monthly consumption.

Household size and employment status are significant predictors of household well water consumption. Increasing a household's size by one person results in a 57 percent increase in total monthly household well water consumption. Farming households use 39 percent more well water per month. Given farming households are located in peri-urban areas only, these results are indicative of spatial variability in household preferences for well water consumption and may be based in part on perceived differences in local water quality. Households with home based businesses use 65 percent more well water than households not running a home business. The demand shifts may be explained in terms of the total household consumer surplus achieved by selective consumption from the two sources and price elasticities. Respondent households view dry season water quality from both sources to be near equivalents. This implies that most households should enjoy a near equivalent welfare increase from consuming water from either source if it were free. Because the cost of consuming an additional cubic meter from the sources differs, the rational household may select the source that provides the greatest net benefit return for the increment. This argument makes intuitive sense. As households become larger or operate home businesses they consume more water. Because municipal and well water are viewed as near equivalents households select well water because they consume water of a near equivalent quality water to municipal water at a lower cost to the household per cubic meter.

Household size, in-house water storage infrastructure, household water quality perceptions, main employment, Mills ratio and whether the household was used for a home business were all tested for single and joint significance and were not found to be significant predictors of municipal water consumption. Similarly, other candidate variables were evaluated as covariates for well water consumption but were found not to individually or jointly significantly improve model performance. The lack of significance of the Mill's ratio indicates it is not necessary to control for selection bias based on household well status.

6.4 THE ECONOMIC VALUE OF HOUSEHOLD WATER IN BUON MA THUOT

The economic value of raw water to households is estimated by evaluating the impact of reducing monthly dry season municipal supplies to the household. Six shortage scenarios ranging between a one and six cubic meter reduction in average monthly supply are evaluated. Because the shadow price of private household well water is heterogeneous across households, the evaluation is conducted for municipal water supplies only. The raw water value is evaluated for the representative household, evaluated as the sample average of surveyed households. The representative household using municipal supplies only has a monthly income of approximately VND3.6 million; contains 4.6 people; has in-house water storage in 83 percent of cases with an average storage capacity of 2.0 cubic meters and consumes approximately 16.6 cubic meters of municipal water per month. For households consuming municipal water only the scenario reductions range between 6 and 36 percent of average monthly household consumption. The representative household using both municipal and private well water supplies generates an income of approximately VND2.24 million per month; contains 4.3 people; has in household water storage capacity approximately 80 percent of the time, operates a home-business in 31 percent of cases and derives their main income source from self-employment 28 percent of cases. For these households the simulated shortfalls range between 11 and 66 of total monthly household consumption from the municipal source. Because the Buon Ma Thuot Water Supply Company could not estimate their average water supply cost per cubic meter an average supply cost of VND2250 per cubic meter is assumed in these estimates. Assuming the average supply cost per cubic meter exceeds the price charge implies some limited over-estimation of supply benefits to the household in these estimates[23]. It is assumed that transmission losses are negligible.

[23]Because the demand functions estimated in the previous section are Marshallian demand functions, and can only provide an approximation the welfare change realized for a supply increment evaluated with a Hicksean demand curve. The assumption made is that the consumer surplus estimate from the Marshallian demand functions are reasonable estimates of the true welfare

The economic impact households relying exclusively on the municipal supply system for water is evident in the household raw water value estimates (Table 6 and Figure 2). For households using municipal supplies only the raw value of water rises from approximately VND1,500 for a one cubic meter shortfall to approximately VND2.1 million for a six cubic meter shortfall. These value estimates reflect these households' inelastic demand for water given the absence of supply substitutes. Households consuming both municipal and private well water have substantially lower at-source economic values for municipal water, ranging between VND285 and VND27,000 for one and six cubic meter decrements respectively. Because households focused on behavioural as opposed to technical or structural responses to changing water (shadow) prices in the contingent behaviour scenarios, these are short-run water values for raw water.

7 CONCLUSIONS

Improvements in the quality of municipal water supplied to Buon Ma Thuot have resulted in increased reliance on and consumption of municipal water by urban and peri-urban households. As Rural Water Supply and Sanitation programs are implemented in regional urban centres around Dak Lak, this situation is likely to be replicated. When increased urban water consumption diverts water from other extractive and in-situ uses, opportunity costs are created raising the question of the (volumetric) extent to which the transfers are justifiable. The short run household raw water values estimated in this research report provide a partial basis for evaluating this issue. The short run household raw water values are directly comparable to net returns generated from allocating an additional cubic meter of raw water from the same source to extractive uses such as irrigated coffee or rice production, or to the social welfare gains made by retaining the water in-situ. Viet Nam's Law on Water Resources calls for this type of comparative analysis for planning river basin development regardless of whether allocation rules are based on principles of rationality, economy and efficiency (Article 4) or fairness and reasonability (Article 20).

Estimates in this research report can also be employed by planning authorities to predict total household demands and the consumer surplus from municipal water supplies when

change that would be derived if the Hicksean functions could be estimated. This is reasonable given the total monthly cost of household water in the scenarios accounts for only a small percentage of monthly household income.

evaluating the economic feasibility of expansions to the municipal supply system in Buon Ma Thuot or municipal system developments in other regional centres in Dak Lak. All that is required to transfer the household demand function estimates is baseline similarity of the study areas, comparable household populations and an expectation that the municipal system developments will deliver water of a similar quality to that currently being delivered in Buon Ma Thuot. Where these conditions are met, the demand estimates in this paper can be used in conjunction with the point expansion approach to estimate the welfare effect of incrementing monthly water supplies to target households. Provided a rough understanding of household demographics is available for the project implementation area, these representative household estimates can then be extrapolated to obtain welfare estimates for all affected households.

Finally, it should be noted that while diversions to urban centres from irrigated agricultural regions imposes immediate opportunity costs on smallholders and other agro-environmental impacts, most of the water diverted to urban centres is not lost from Dak Lak's hydrological system. The majority of household water usage returns water, often almost immediately, to the municipal sewerage system, which in turn may be returned to agro-environmental areas after processing. This point has gone largely unrecognised in the household water demand literature. To model the broader social welfare impacts of rural-urban water diversions and return flows from these diversions requires an integrated approach for modelling the impacts of land and water resource use.

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9 TABLES AND FIGURES

Table 1: Descriptive statistics

Variable	Unit	Obs.	Mean	Std Dev	Min	Max
Basic household information						
Household size	Number	291	4.66	2.3002	1	21
Main occupation is farming	Yes=1	291	0.10		0	1
Household income < VND2 million per month	Yes=1	291	0.18		0	1
Household income VND2-4 million per month	Yes=1	291	0.47		0	1
Household income VND4-6 million per month	Yes=1	291	0.19		0	1
Household income VND6-8 million per month	Yes=1	291	0.05		0	1
Household income >VND8 million per month	Yes=1	291	0.05		0	1
Did not report household income	Yes=1	291	0.06		0	1
Operate a home business	Yes=1	291	0.28		0	1
Water sources and usage						
Sources used by the household						
Municipal water only	Yes=1	291	0.56		0	1
Household monthly consumption	m^3	163	15.98	15.19	4.02	123
Per capita daily consumption	Lt	163	120.06	105.88	14.81	841.53
Municipal water and private well	Yes=1	291	0.22		0	1
Household monthly municipal water consumption	m^3	65	9.12	9.53	1	58
Per capita daily municipal water consumption	Lt	65	70.22	65.97	4.68	316.93
Municipal connection situation						
Share water with neighbour	Yes=1	291	0.05		0	1
Quality of (dry season) water good or better	Yes=1	291	0.65		0	1
Quality of (wet season) water good or better	Yes=1	291	0.60		0	1
Experienced water shortage in past 12 months causing substantial inconvenience	Yes=1	291	0.08		0	1
Well water situation						
Have a dug or drilled well	Yes=1	291	0.25		0	1
Quality of (dry season) water good or better	Yes=1	72	0.69		0	1
Quality of (wet season) water good or better	Yes=1	72	0.55		0	1
Use motorized pump to bring water to surface	Yes=1	72	0.83		0	1
Motorized pump HP	HP	59	1.12	0.411	0.48	2.5
Experienced water shortage in past 12 months causing substantial inconvenience	Yes=1	71	0.04		0	1
Water storage tank situation						
Have in house water storage	Yes=1	291	0.88		0	1
In house water storage is a storage tank	Yes=1	257	0.81		0	1
Average storage tank capacity	m^3	208	2.41	1.86	0	16
Municipal water goes to storage	Yes=1	257	0.82		0	1
Private well water goes to storage	Yes=1	257	0.16		0	1
Both municipal and well water go to the same storage	Yes=1	257	0.03		0	1

Variable	Unit	Obs.	Mean	Std Dev	Min	Max
Household knowledge of municipal water tariff						
Municipal water tariff correctly described	Yes=1	291	0.15		0	1
Households treating water by activity						
Bathing	None=0	291	0.0		0	1
Meal preparation	None=0	291	0.0		0	1
Drinking	None=0	291	0.81		0	1
Cleaning	None=0	291	0.0		0	1
Laundry	None=0	291	0.0		0	1
Gardening	None=0	291	0.0		0	1

Table 2: Household water treatment

Variable	Bathing		Meal preparation	Drinking		Cleaning		Laundry		Gardening	
Number of households by source (total n=291)											
Municipal water (MW)	236		267	230		225		222		49	
Well water (WW)		44					50		61		31
Bottled water (BW)					48						
Treatment by source	**MW**	**WW**	**MW**	**MW**	**BW**	**MW**	**WW**	**MW**	**WW**	**MW**	**WW**
No treatment	177	29	186	10	44	167	37	167	46	39	27
Run water intro storage and wait for impurities to sink	59	15	80	45		58	13	55	15	10	5
Boil water				218	4						
Using other filter				35							
Percentage of households not treating water	75	66	70	4	92	74	74	75	75	80	87
Percentage of households not treating water or waiting for impurities to sink	100	100	100	24	92	100	100	100	100	100	100

Table 3: Parameter estimates of household well status probit model. Maximum Likelihood estimation results

	Coefficient	z-ratio
Dependent variable: log likelihood of having a household well		
Monthly household income	-0.0001***	(2.70)
	(0.00)	
In-house water storage (1=No)	-0.05	(0.17)
	(0.27)	
In-house water storage capacity in cubic meters (log)	0.47***	2.94
	(0.16)	
Faming is main household employment (1=Yes)	0.71*	1.92
	(0.37)	
Self-employment is main household employment (1=Yes)	0.48**	2.08
	(0.23)	
Constant	-0.42*	(1.82)
	(0.23)	
Log pseudo-likelihood	-100.40***	
Wald chi2(5)	23.04	
Pseudo R2	0.10	
Observations	171	

Notes: *, ** and *** denote statistical significance at the 0.10 level, 0.05 and 0.01 level respectively. Numbers in parentheses are asymptotic standard errors.

Table 4: Random effects generalised least squares parameter estimates of household demand function for households using municipal water only.

	Coefficient	z-ratio
Dependent variable: log of total municipal water consumption per month		
Municipal water price (log)	-0.062*** (0.005)	(13.12)
Household size (log)	0.6012*** (0.059)	10.04
In-house water storage (1=No)	-0.267*** (0.058)	(4.63)
In-house water storage capacity in cubic meters (log)	0.184*** (0.037)	4.98
Constant	2.17*** (0.106)	20.55
Wald chi2(4)	430.41	
Adjusted R-square	0.43	
Observations	329	
Groups	108	

Notes: *, ** and *** denote statistical significance at the 0.10 level, 0.05 and 0.01 level respectively. Numbers in parentheses are asymptotic standard errors.

Table 5: Seemingly unrelated regression parameter estimates of household demand functions for municipal and household well water.

	Coefficient	t-ratio
Dependent variable: household municipal water consumption per month (log)		
Municipal price per cubic meter (log)	-0.509*** (0.049)	-10.39
Well shadow price per cubic meter (log)	0.314*** (0.072)	4.34
Monthly household income (log)	0.337*** (0.066)	5.08
Motorised well pump capacity (HP)	- 0.277*** (0.095)	-2.93
Constant	-1.143 (1.086)	-1.05
F-statistic	36.35	
Adjusted R-squared	0.31	
Observations	285	
Dependent variable: household well water consumption per month (log)		
Well shadow price per cubic meter (log)	- 0.324*** (0.074)	-4.40
Municipal price per cubic meter (log)	0.438*** (0.050)	8.77
Household size (log)	0.574*** (0.106)	5.44
Motorised well pump capacity (HP)	0.623*** (0.107)	5.82
In-house water storage (1=No)	0.273 (0.176)	1.55
In-house water storage capacity in cubic meters (log)	0.085* (0.048)	1.77
Farming is main household employment (1=Yes)	0.334*** (0.127)	2.63
Household operates a home business (1=Yes)	0.514*** (0.097)	5.29
Constant	-1.019 (0.643)	-1.58
F-statistic	24.97	
Adjusted R-squared	0.37	
Observations	285	
Correlation between household municipal water consumption per month (log) and household well water consumption per month (log)	-.64	
Breusch-Pagan test of independence: chi2(1)	115.79***	

Notes: *, ** and *** denote statistical significance at the 0.10 level, 0.05 and 0.01 level respectively.

Numbers in parentheses are asymptotic standard errors.

Table 6: Short run raw water value of municipal water supplies in monthly household use

	Price (VND)	Elasticity	Average monthly household consumption (m³)	Short-run value of raw water ***(VND)*** Reduction from the average monthly consumption (m³)					
				1	2	3	4	5	6
Total									
Municipal supplies only	2,250	(0.062)	16.57	1,594	10,187	40,811	146,847	537,437	2,131,885
Municipal and private well supplies	2,250	(0.486)	9.13	285	1,304	3,424	7,303	14,253	27,294
Per cubic meter									
Municipal supplies only				1,594	5,094	13,604	36,712	107,487	355,314
Municipal and private well supplies				285	652	1,141	1,826	2,851	4,549

Figure 1: Consumer water demand curve

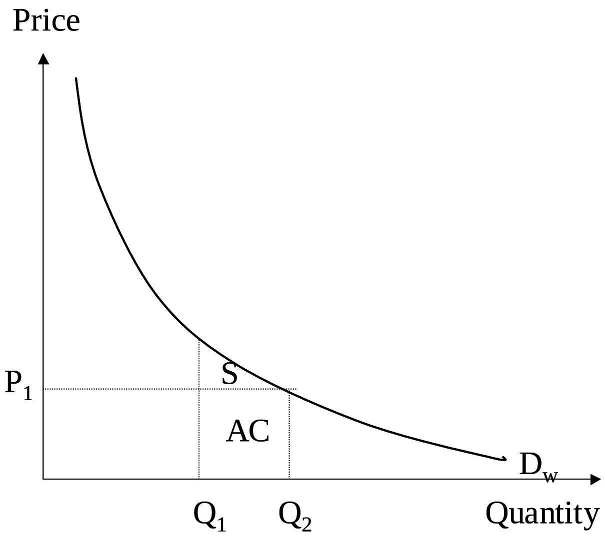

Figure 2: Short run raw water value of municipal water in monthly household use (data from Table 6)