Estimating household water demand using revealed and contingent behaviors: Evidence from Vietnam

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[1] This article estimates the water demand of households using (1) municipal water exclusively and (2) municipal water and household well water in the capital city of Dak Lak Province in Vietnam. Household water demands are estimated using a panel data set formed by pooling household records of metered municipal water consumption and their stated preferences for water consumption contingent on hypothetical water prices. Estimates show that households using municipal water exclusively have very price inelastic demand. Households using municipal and household well water have more price elastic, but still inelastic, simultaneous water demand and treat municipal water and household well water as substitutes. Household water consumption is influenced by household water storage and supply infrastructure, income, and socioeconomic attributes. The demand estimates are used to forecast municipal water consumption by households in Buon Ma Thuot following an increase to the municipal water tariff to forecast the municipal water supply company's revenue stream following a tariff increase and to estimate the consumer surplus loss resulting from municipal water supply shortages.

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1. Introduction

[2] Household water demand analyses are an economic cornerstone of urban water supply planning, demand side water management, and the design of efficient water tariffs. Meta-analyses profiling the household water demand literature concentrate on studies from developed economies [*Espey et al.*, 1997; *Arbues et al.*, 2003; *Dalhuisen et al.*, 2003]. The developed economy household water demand literature is typically based on aggregate or microlevel household data that includes the amount of water consumed by a household from a single municipal water supplier over some time period, an increasing or decreasing block tariff, household socioeconomic attributes, and sometimes climatic and structural factors. The standard finding is that household water demand is price and income inelastic. Price inelasticity is attributed to water having few substitutes in basic uses, and to water expenditures normally accounting for a small percentage of household income, which results in households not being responsive to water pricing signals [*Arbues et al.*, 2003].

[3] Less work has been directed toward estimating household water demand in developing economies. *Strand and Walker* [2005] estimated a price elasticity of -0.32 using a household level survey data set from seventeen cities in Central America and Venezuela. Households drawing water from more than one source were shown to have source specific water demand, and having a water connection was found to be a stronger determinant of household water demand than the pooled water price. Using data from seven Cambodian towns, *Basani et al.* [2008] estimated households' own price elasticity for municipal water between -0.40 and -0.50. Combining household data from El Salvador and Honduras, *Nauges and Strand* [2007] estimated a non−tap water demand elasticity as a function of water cost, defined as the sum of the water purchase price and the labor opportunity cost of water hauling, of between -0.40 and -0.70. *Rietveld et al.* [2000] estimated an own price elasticity of -1.2 for a cross section of Indonesian households. *Acharya and Barbier* [2002] estimated linear water demands for Nigerian households that (1) hauled water exclusively, (2) purchased vendor water exclusively, or (3) hauled water and purchased vendor water. The estimated price elasticity of households purchasing vendor water exclusively was -0.067, whereas the estimated own price elasticity of vendor water by households that hauled water and also purchased vendor water was -0.073.

[4] A variable water price is needed to estimate the price elasticity of household water. Water can be priced on the basis of a flat rate, however, or unpriced, in the sense of not having a tariff, as occurs when a household draws water from a private household well. Both of these situations complicate the estimation of household water demand, but both, and especially the latter, are frequent features of household water supply and usage in developing and rural

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thetical markets and use these to simulate individual preferences for the allocation of scarce resources [*Bateman et al.*, 2002], can be used to estimate the relationship between hypothetical water prices and household water consumption. These stated preference price consumption points can then be used to estimate household water demand functions. When available, the water purchase history of a household can be used as an empirical anchor point to investigate likely household water consumption in novel water pricing situations. Convergent validity between a household's historical water purchases given real water prices and stated water purchased based on hypothetical water prices shows the same underlying preference structure is used in both preference elicitation formats. Analyses pooling revealed and stated preference data generally show data pooling increases the efficiency and robustness of estimated parameters, especially when small data sets are used [*Englin and Cameron*, 1996; *Haab and McConnell*, 2003; *Hanley et al.*, 2003; *Birol et al.*, 2006].

[5] This article estimates the demand for delivered water of (1) households using municipal water exclusively and (2) households consuming municipal water and household well water in Buon Ma Thuot, Vietnam. Buon Ma Thuot is the capital of Dak Lak Province, which is located in the Central Highlands region of Vietnam. The municipal water supply system was upgraded and expanded in 2001–2003, and these supply system improvements have resulted in households connected to the municipal system increasing water consumption from this source. Buon Ma Thuot's municipal water supply system draws mainly groundwater from regions dominated by irrigated agriculture, and increasing municipal water consumption in Buon Ma Thuot increasingly imposes pumping and stock opportunity costs on irrigators in these regions. The autonomous state agency responsible for operating the municipal water supply system is meant to operate at full cost recovery. The fixed VND 2,250 (1 U.S. dollar $\approx$ 15,500 Vietnamese dong) per cubic meter tariff the municipal water supply company charges for household water is less than the VND 4,000 per cubic meter average cost the company estimates it incurs to deliver water to households in Buon Ma Thuot however. All households receiving municipal water in Buon Ma Thuot are metered and receive monthly household water bills on the basis of their metered water consumption.

[6] Approximately 75% of all permanent households in Buon Ma Thuot are connected to the municipal water supply system. A percentage of households connected to the municipal water supply system consume water from at least one other source, such as private wells or water vendors. Little is known about household water consumption patterns from nonmunicipal water sources in Buon Ma Thuot, nor why households consume water from these sources over municipal water. *Madanat and Humplick* [1993] found that households in Pakistan drew water from different sources for specific household uses, and it is reasonable to expect the same in Buon Ma Thuot. Nothing is known about how households using secondary water sources in Buon Ma Thuot would alter their water consumption pattern following changes in the supply attributes of water from either the municipal or a secondary source. These substitution strategies carry important economic and water planning implications however, meaning a system of conditional water demands for households using more than one water source should be estimated.

[7] This article makes two main contributions to the household water demand literature. First, the article adds to the sparse literature that estimates single and simultaneous household water demand in Southeast Asia. Second, a novel revealed and stated preference approach is used to estimate own and cross-price elasticities of household water. Household water demand estimates are constructed from a survey data set that pools households' actual metered municipal water consumption given the existing fixed tariff, and households' stated water consumption preferences contingent on hypothetical water tariffs. The stated preference approach is based on the contingent behavior method, which works by eliciting individuals' intended behavioral response if a hypothetical situation were to occur [*Hanley et al.*, 2003]. In this case the contingent behavior is how the household would change their water consumption behavior in seven household usages following a change to water tariffs. *Acharya and Barbier* [2002] previously used a contingent behavior approach to measure household water demand in Nigeria, which they estimated as a function of real and hypothetical vendor water prices and water hauling times.

[8] In the remainder of this article the conceptual household water demand model, estimation and survey approaches are first described. Following a brief descriptive analysis of the survey data, household water demands are estimated from the panel data set. Policy implications are discussed in section 5, and the household water demand estimates are used to forecast household municipal water consumption following an increase in the municipal water price, and also to forecast the municipal water supply company's revenue stream. Consumer surplus losses imposed by binding water supply constraints are evaluated in section 6, while the section 7 concludes.

2. Specification and Estimation Technique

2.1. Modeling Household Water Demand

[9] Household water demand is a function of an underlying decision making process that accounts for water usage preferences and household constraints on acquiring water [*Larson et al.*, 2006]. When household labor is needed to collect and prepare water, a nonseparable conceptual model is needed to estimate household water demand because the household must choose between allocating its scarce labor to water collection and preparation activities or to income generating activities. *Acharya and Barbier* [2002] develop a household production model that characterizes the household decision making framework when two water sources are available, with one source being free but requiring labor input, and the other priced and not requiring labor input. The household seeks to maximize utility from water given the water sources available and subject to household income and labor constraints. The end result is the household water demand function, conditional on water source:

$$Q_j = Q_j(p_p, s_c, \mathbf{A}_p, \mathbf{A}_c, \mathbf{Z}) \quad (1)$$

is the water quantity used from source j, p_p is the s_c is the shadow price of collected water, which is the marginal opportunity cost of foregone work income, $\mathbf{A}_p$, $\mathbf{A}_c$, are two vectors describing water quality attributes, such as turbidity, smell, and taste, of priced and collected water respectively, and $\mathbf{Z}$ is a vector of household specific characteristics, including income and labor potential. When water is perfectly substitutable between sources, the utility maximizing household consumes water from both sources until the marginal rate of substitution from purchasing water and collecting water are equal, meaning the marginal opportunity cost of foregone work income equals the marginal water price. This household decision framework includes two corner solutions. When the opportunity cost of foregone work income due to water collection and preparation always exceeds the marginal water price, the household always consumes priced water only. Conversely, when the marginal water price always exceeds the marginal opportunity cost of labor, the household will always collect water.

2.2. Demand Estimation

2.2.1. Household Well Status

[10] To obtain unbiased household water demand estimates with a parametric econometric approach requires that private well water consumption in Buon Ma Thuot results from a random selection process. Latent variables may contribute toward determining whether a household draws water from a well source however. This potential source of sample selection bias is controlled for in this research using *Heckman*'s [1979] two step estimation procedure. In the first step, the discrete choice dependent variable (d_i) is specified to equal one if the household has a private well and zero if they do not. Assuming a normal probability distribution for the error term (u_i), the decision model in probit form is

$$\Pr(d_i = 1) = \Pr(\mathbf{x}_i\boldsymbol{\beta} \prec u_i) = \Phi(\mathbf{x}_i\boldsymbol{\beta}) \tag{2}$$

where $\mathbf{x}_i$ is a vector of explanatory variables describing the household's well status, $\boldsymbol{\beta}$ a vector of unknown coefficients to be estimated, and $\Phi(\mathbf{x}_i\boldsymbol{\beta})$ is the cumulative normal distribution. The inverse Mill's ratio is calculated using the estimated parameters of the probit model and included in the second stage household water demand estimates

$$M_i = \frac{\phi\left(\mathbf{x}_i\hat{\boldsymbol{\beta}}\right)}{\left[1 - \Phi\left(\mathbf{x}_i\hat{\boldsymbol{\beta}}\right)\right]} \tag{3}$$

where $\Phi(.)$ and $\phi(.)$ are respectively the univariate standard normal cumulative distribution and the probability density functions.

2.2.2. Conditional Household Water Demand Functions

[11] The assumed water demand function for households using municipal water exclusively is

$$\ln(Q_m) = c_1 + a_1 \ln(p_m) + a_2\mathbf{Z} + \varepsilon_1 \tag{4}$$

Households using water from municipal and private well sources have simultaneous water demand defined by

$$\ln(Q_m) = c_2 + b_{m1} \ln(p_m) + b_{m2} \ln(s_w) + b_{m3}\mathbf{Z} + \varepsilon_2 \tag{5}$$

$$\ln(Q_w) = c_3 + b_{w1} \ln(p_m) + b_{w2} \ln(s_w) + b_{w3}\mathbf{Z} + \varepsilon_3 \tag{6}$$

where the municipal water price is p_m, s_w is the shadow price of household well water, $\mathbf{Z}$ describes household socioeconomic characteristics including water supply infrastructure such as storage tanks and booster pumps, and also the inverse Mill's ratio, ε_i the normally distributed idiosyncratic error term, and the remainder are coefficients to be estimated. Notice these demand specifications exclude the costs of preparing water for use, such as filtering or boiling water before drinking, because descriptive analyses, which are discussed later in this article, suggest these are likely numerically immaterial. The demand equations also exclude water quality attributes, again because descriptive analyses showed Buon Ma Thuot's survey respondents viewed water quality as being near equivalent between municipal and household well sources, and also because subjective reports of water quality are likely correlated with household specific socioeconomic attributes [*Whitehead*, 2005].

3. Empirical Application

[12] The schedules of household water consumption as a function of water prices were constructed in this analysis by pooling the observed and contingent behavior water consumption data of urban and periurban households in Buon Ma Thuot. The water consumption observed behavior data for each household was the household's metered municipal water consumption at the VND 2,250 per cubic meter municipal water tariff. The contingent water consumption behavior data for each household was constructed by estimating how the household would alter its monthly water consumption in seven household usages if a new hypothetical (shadow) water price was implemented.

[13] Survey development is discussed in detail by *Cheesman et al.* [2007]. The survey collected household background data, including details on in-household water supply infrastructure, and estimated actual and contingent household water consumption in seven main household water uses, with these defined in pretesting: (1) bathing and washing, (2) meal preparation, (3) drinking, (4) cleaning, (5) laundry, (6) outside (generally gardening), and (7) home business.

[14] To estimate the revealed and stated household water preferences by usage, the survey enumerator first assisted the respondents to estimate their normal daily household water consumption by source for the seven household usages. To do this, the enumerator walked through the household and identified with the respondents where activities using water occurred. Following this initial identification, the enumerator worked with the respondents to estimate the amount of water consumed in each of the seven main household uses during a normal day. Because different household members are generally responsible for specific water using activities, both the male and female household heads participated where possible. Having both

Thomas and Syme, 1988], because the respondents audited the other's answers and there was open discussion on points of difference. The household members estimated their daily water consumption by usage via observation and demonstration. For water usages that were not daily, weekly consumption figures were estimated.

[15] After household daily or weekly water consumption in the seven household usages were estimated, the enumerator extrapolated the household's monthly water consumption and expenditure by water source and household use. The household's estimated municipal water consumption was compared to the household's most recent available municipal water bill to check whether the respondents accurately estimated their monthly municipal water consumption. Then, to estimate the monthly municipal water cost by usage, the estimated monthly municipal water consumption in each use was multiplied by the VND 2,250 per cubic meter municipal water tariff. The same procedure was followed to calculate the monthly cost of private well water by use, but well water consumption was multiplied by VND 450 per cubic meter shadow price, which was the average well water extraction cost estimated from pretesting data. The well water shadow price was constructed as the sum of labor and pump fuel costs only, with these being constructed from the average daily wage and fuel price observed from the pretesting respondents. It would have been preferable to separately estimate a well water shadow price for each household, however pretesting showed this preferable approach was prohibitively time consuming, distracting, and often lead to the enumerators incorrectly calculating the shadow price. Because the survey focus groups, pretests and discussions with local authorities suggested households were relatively homogenous in the way they acquire, store, and use household well water, the common shadow price approach was favored.

[16] After the enumerator checked that the respondents understood their monthly water cost by household usage and source, this water usage and expenditure schedule was used as an anchoring point for the contingent behavior scenarios. In the contingent behavior scenarios, the hypothetical price change was an increasing or decreasing fixed municipal water tariff or shadow well water price. For each water source used, households were presented with two contingent behavior scenarios, resulting in each household having three observations per water source used; one "revealed" observation on the basis of observed water consumption at the real (shadow) tariff, and two stated preference contingent behavior observations on the basis of hypothetical water tariffs. Municipal water users each received one hypothetical price lower than the current VND 2,250 tariff, either VND 500, VND 1,000, or VND 1,750, and one higher hypothetical price, either VND 2,500, VND 5,000, VND 7,500, VND 10,000, VND 15,000, or VND 25,000. The same approach was followed to elicit monthly well water consumption contingent on hypothetical well water shadow prices, using the hypothetical prices VND 100, VND 250, VND 1,000, VND 1,500, VND 2,000, VND 2,500, VND 3,000, VND 4,500, or VND 7,500.

[17] For each hypothetical water price, the enumerator first calculated and told respondents their revised monthly household water expenditure, assuming household consumption by source did not change. This approach allowed households to see their revised monthly water expenditure decomposed by household use and by water source. Respondents were then asked whether they would change household water consumption given their new water budget. Households stating they would alter water consumption worked with the enumerator to determine how they would alter water consumption in the seven household uses. Behavioral, technical, or structural modifications could be employed to change household water consumption, however most respondents focused on short-term behavioral adjustments, either changing the amount of water consumed, adopting water recycling, or substituting consumption between the water sources available to them. After respondents had revised their household water consumption, the enumerator calculated the household's new water consumption and expenditure profile. Respondents satisfied with their new water profile proceeded to the next scenario. The enumerator worked with unsatisfied households to revise their water consumption, with this procedure being repeated until the respondents accepted their new water profile. The procedural logic was the same for the well water scenarios.

4. Results, Discussion, and Policy Implications

4.1. Descriptive Statistics

[18] The household survey was completed in mid 2006 and obtained 291 usable responses. Descriptive analyses reveal the respondent households viewed municipal and household well water quality favorably, but with some seasonal and income-based variation; that households predominantly used municipal and well water in the household; had in-household water storage infrastructure and automated well water extraction; excepting drinking water did not devote labor to preparing water; and did not know the municipal water tariff (Table 1).

[19] Approximately half of the respondent households consumed municipal water exclusively, and these households averaged 560 L total consumption per day on average, roughly equivalent to 120 L per capita per day. The 22% of households augmenting municipal water with household well water only, or with well water and water from another source, consumed approximately 70 L of municipal water per capita per day. Almost nine out of ten respondent households reported having some form of in-house water storage infrastructure. Cement water storage tanks were installed in almost seven out of every ten households surveyed. These cement storage tanks had a 2.4 m^3 average storage capacity, which is sufficient for 4.5 days of water supply to the statistically average sized household consuming 120 L per capita per day. Approximately 85% of households using well water used motorized pumps to draw water. More detailed descriptive analyses are provided by *Cheesman et al.* [2007].

4.2. Household Water Demand Estimates

[20] Comparing the descriptive statistics and results from the contingent behavior scenarios showed a percentage of households who reported not having access to a private well in the survey's background section stated they would draw water from a private household well if the municipal water price were to increase. For estimation purposes, respondents who were using municipal water and stated they would use household well water in at least one of the contingent

Household Descriptive Statistics

Variable	Unit	Observations	Mean	Standard Deviation	Min	Max
Basic Household Information						
Household size	number	291	4.66	2.30	1	21
Main occupation is farming	yes = 1	291	0.10		0	1
Monthly household income	VND Mil	291	3.29	2.27	0.25	20.00
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 usage	m^3	163	15.98	15.19	4.02	123
Per capita daily usage	Lt	163	120.06	105.88	14.81	841.53
Municipal water expenditure as a percent of monthly household income	%	119	1.37	1.67	0.04	17.33
Municipal water and private well	yes = 1	291	0.22		0	1
Household monthly municipal water usage	m^3	94	9.12	9.53	1	58
Per capita daily municipal water usage	Lt	94	70.22	65.97	4.68	316.93
Municipal water expenditure as a percent of monthly household income	%	92	0.81	0.75	0.05	4.05
Municipal connection situation						
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	0.41	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
Household Knowledge of Municipal Water Tariff						
Municipal water tariff correctly described	yes = 1	291	0.15		0	1

behavior scenarios where categorized as having access to municipal and household well water. Households indicating in the contingent behavior scenarios that they would only use municipal water were categorized as municipal only households. Categorizing using this basis resulted in a subgroup of 133 households using municipal water exclusively, and a 92 household subgroup using municipal and well water. The remaining 66 households that drew water from other secondary sources were excluded from the demand analysis because of small subgroup numbers. Eleven of the 133 households using municipal water exclusively had missing income replaced with their subgroup's average income. Similarly, four of the 92 households drawing well and municipal water had missing household income replaced by their subgroup average. Three influential outlier observations were dropped from the municipal water subgroup, and two from the well water subgroup. This procedure resulted in a final sample of 130 households using municipal water only, and 90 households using municipal and household well water.

[21] The accuracy of the household water demand estimates partly depends on respondents being able to accurately estimate their monthly household water consumption. Pairwise correlations between the monthly household municipal water consumption that was estimated by respondents and the household's actual monthly municipal water consumption from the most recent municipal water bill was used to evaluate the accuracy of household water consumption estimates. The pairwise correlation for households using municipal water exclusively was 0.86, significant at the 1% level. Households using both municipal and well water had a pairwise correlation of 0.93, also significant at the 1% level. These pairwise correlations suggest respondent households could estimate their household water consumption with an acceptable level of accuracy. Assuming that households using municipal and well water could estimate their daily well water consumption with a level of accuracy similar to their municipal water consumption suggests these households consume approximately 100 L of household well water per capita per day, meaning aggregate well and municipal consumption for these households is roughly

[a]	Coefficient[b]	z Ratio
Monthly household income	−1.52E-07*** (5.20E-08)	−2.92
In-house water storage (1 = yes)	0.318 (0.262)	−1.21
In-house water storage capacity (m^3)	−0.002 (0.003)	−0.51
Farming is main household employment (1 = yes)	0.723** (0.300)	2.40
Self-employment is main household employment (1 = yes)	0.246 (0 0.207)	1.19
Constant	−0.161 (0.284)	−0.57
Log likelihood	−138.890***	
Likelihood ratio chi2(5)	19.89	
Pseudo R2	0.07	
Percentage correct predictions (overall)	65	
Observations	220	

[a]Probability of having a household well.
[b]Here ** and *** denote statistical significance at the 0.05 and 0.01 level, respectively. Numbers in parentheses are asymptotic standard errors.

170 L per capita per day. These aggregate results suggest that at the 2006 prices, households using private well water and municipal water obtained around 60% of their daily water needs from their household well.

[22] To test the assumption that respondents' revealed and stated preferences for household water consumption as a function of price were derived from the same underlying preference structure dummy variables were used to distinguish the contingent behavior data from the revealed preference data, and included in the system of demand equations to test for equality. The coefficient for the contingent behavior dummy variable was insignificant in all estimates, supporting the null hypotheses that the observed and contingent behavior data shared a common underlying preference structure.

4.2.1. Household Well Status

[23] The best fitting probit estimate for the 220 municipal only and municipal and well households is significant at the 1% level (Table 2). Increasing household income decreases the probability that a household had a well, which is consistent with observations from the household water consumption profile. Farming households were more likely to have a well, which is unsurprising given farms are primarily located in periurban areas and most farms use dug wells for irrigation. Pairwise correlations between farming and income, and self-employment and income, showed these variables were not significantly correlated. The inverse Mill's ratio was calculated from these probit model estimates.

4.2.2. Municipal Water Demand Estimates

[24] Water demand by households using municipal water only was estimated using random effects generalized least squares, because this approach allows time invariant household specific explanatory variables to be included in the demand equation. The balanced panel data set includes 390 observations, comprising the two contingent behavior responses and one revealed preference response for each of the 130 households using municipal water only. 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

$$\begin{aligned}\ln\left(Q_{m,i,t}\right) = {} & c_1 + a_1 \ln\left(p_{m,i,t}\right) + a_2 D_{know_i} \\ & + a_3 \ln\left(p_{know_{i,t}}\right) + a_4 \ln(inc_i) \\ & + a_5 \ln(hhsize_i) + a_6 D_{store_i} + a_7 \ln(store_i) \\ & + a_8 farm_i + a_9 own_i + a_{10} mills_i + w_{i,t}\end{aligned} \quad (7)$$

where ln denotes logarithms to base e and Q_m is the dependent variable, which is the household's monthly municipal water consumption in cubic meters. The explanatory variables are the municipal water price (p_m), a dummy variable differentiating respondents who knew the municipal water price charged by the water supply company from respondents who did not (D_{know_i}), an interaction measuring the price elasticity effect of knowing the municipal water tariff ($p_{know_{i,t}}$), income (inc), household size ($hhsize$), measured by the number of people living in the household for more than 5 months a year, a dummy variable describing whether the household has in-house water storage (D_{store}), household water storage capacity in cubic meters ($store$), dummy variables differentiating farming and nonfarming households ($farm$) and households running a home business from those who do not (own), and the inverse Mill's ratio calculated from the probit estimate ($mills$). The additive composite error (w) includes a term for individual specific unobserved heterogeneity (u), and the usual idiosyncratic disturbance term (e). Individual specific unobserved heterogeneity and the random disturbance term are assumed to be uncorrelated, and to have zero means and constant variances. The dummy and interaction explanatory variables for knowing the municipal water tariff and in-household water storage were coded using *Battese*'s [1997] approach, which overcomes potential estimation biases resulting from assigning small values to zero valued observations before transforming these data into natural logarithms. Roughly 75% of the households with in-house water storage infrastructure installed this infrastructure before 2003 when the municipal water supply system upgrade was completed in Buon Ma Thuot. Water storage infrastructure was therefore assumed to be exogenous to current water consumption.

[25] The estimated municipal water demand function is significant at the 1% level (Table 3) and the coefficients for the retained covariates are generally significant and have signs consistent with expectations and previous household water demand literature. A Hausman test confirmed the orthogonality conditions imposed by the random effects estimator were not violated. The Breusch-Pagan Lagrange multiplier test rejected the null hypothesis that the variance of u_i equaled zero, thereby showing that there are significant individual effects in the demand equation, meaning that estimating the demand function with pooled ordinary least squares would be inappropriate [*Baum*, 2006].

[26] The −0.059 own price elasticity estimate is significant at the 1% level, and shows that households using municipal water only have very price inelastic water demand. By example, the price elasticity estimate shows that increasing the municipal water tariff by 20% would cause households using municipal water only to reduce their average monthly water consumption by just 1.2% over the

Random Effects Water Demand Estimates for House-

Dependent Variable[a]	Coefficient[b]	z Ratio
Municipal price per cubic meter (log) (VND)	−0.059**** (0.005)	−12.71
Know water tariff (1 = no, 0 = yes)	−0.096 (0.134)	−0.72
Municipal price per cubic meter (log) households knowing water tariff (VND)	−0.022** (0.013)	1.71
Monthly household income (VND) (log)	0.141** (0.085)	1.66
Household size (log)	0.507**** (0.086)	5.91
In-house water storage (1 = no, 0 = yes)	−0.144* (0.092)	−1.57
In-house water storage capacity (log) (m^3)	0.110*** (0.051)	2.17
Farming (1 = yes, 0 = no)	−0.016 (0.153)	−0.10
Operate a home business (1 = yes, 0 = no)	0.101 (0.079)	1.28
Mills ratio	0.086 (0.150)	0.57
Constant	0.161 (1.139)	0.14
Wald chi2(9)	294.24	
Adjusted R square	0.43	
Observations	390	
Groups	130	
Hausman test for random effects Ho[c]		
chi2(2)	0.10	
Prob > chi2	0.95	
Breusch and Pagan Lagrangian multiplier test for random effects: H0: Var(u) = 0		
chi2(1)	349.19	
Prob > chi2	0.00	

[a]Log of total municipal water usage per month, m^3.

[b]Here *, **, ***, and **** denote statistical significance at 15, 10, 5, and 1% level, respectively. Numbers in parentheses are asymptotic standard errors.

[c]Difference in coefficients not systematic.

short run. This household own price elasticity estimate is more inelastic than previous estimates from developing countries for households using piped water exclusively. Households that knew the municipal water tariff were marginally more responsive to municipal water price changes, with an own price elasticity of −0.081. Household income elasticity is significant at the 10% level, and shows that a 10% increase in monthly household income lifts monthly municipal water consumption by 1.4% on average. Monthly household municipal water consumption is also increased as the number of permanent residents increases, such that doubling the number of permanent residents increases monthly household consumption by approximately 50%. The significant dummy variable for in-household storage shows households with water storage infrastructure consume more water than households without storage, irrespective of the total storage capacity. The significant elasticity estimate for water storage capacity shows increasing in-household water storage capacity further increases total monthly municipal water consumption. Coefficients for operating a home business, operating a farm, and the inverse Mills ratio are insignificant. The inverse Mill's ratio estimate suggests there is no selection bias in the demand model due to household well status.

4.2.3. Simultaneous Household Water Demand From Municipal and Well Sources

[27] Demand estimates for households simultaneously using municipal and well water were estimated from the unbalanced panel data set comprising 357 observations from 90 households using a seemingly unrelated estimation approach. Seemingly unrelated estimation combines the parameter estimates, and the variance and covariance matrices from separately estimated municipal and well water demand equations into a single parameter-vector and simultaneous variance covariance matrix of the robust type. The seemingly unrelated estimator generates the same coefficient estimates as seemingly unrelated regression (SUR), is less efficient than SUR, but is robust to both cross-equation correlations and between group heteroskedasticity. Seemingly unrelated regression assumes homoskedasticity, however this assumption is likely to be violated in this data set, with the result that SUR would estimate incorrect standard errors. The practical implication is the selected approach traded off some estimation efficiency in favor of additional estimation robustness.

[28] Simultaneous municipal and well water demand are defined using the same covariates

$$\begin{aligned}\ln\left(Q_{j,i,t}\right) = c_j &+ b_{j1}\ln\left(p_{m,i,t}\right) + b_{j2}D_{know_i} \\ &+ b_{j3}\ln\left(p_{knowm_{i,t}}\right) + b_{j4}\ln\left(s_{w,i,t}\right) \\ &+ b_{j5}\ln(inc_i) \\ &+ b_{j6}\ln(hhsize_i) + b_{j7}pc_i + b_{j8}D_{store_i} \\ &+ b_{j9}\ln(store_i) + b_{j9}farm_i + b_{j10}own_i \\ &+ b_{j11}mills_i + e_{j,i,t} \qquad (8)\end{aligned}$$

where s_w is the shadow price of household well water, pc denotes pump horsepower, and the other variables have been defined previously. Approximately 75% of the respondents purchased their water storage infrastructure before 2003, and approximately 85% purchased their water pumps before 2003. These covariates are therefore assumed to be exogenous to current household water consumption.

[29] The estimated models are both significant at the 1% level (Table 4). The estimated own price elasticities of −0.51 for municipal water and −0.44 for well water are more elastic than households using municipal water only, but still inelastic. Households who knew the municipal water price did not have statistically different own price elasticity for municipal water in this estimate. The cross-price elasticity of municipal water is 0.46, and 0.35 for household well water, showing that water from these sources are substitutes rather than compliments. Households knowing the municipal water price have more elastic, but still inelastic, cross-price elasticity for municipal water, significant at the 15% level. The observed elasticities are similar to those in *Nauges and van den Berg* [2007] for households in Sri Lanka using piped and nonpiped water. Cross-equation tests show the own and cross-price elasticity of municipal water are inverse, meaning a one per cent increase in the municipal water price causes an equal percentage shift out of municipal water into well water. The same cross-equation symmetry was rejected for well water, where increasing the well water shadow price results in a less than proportional percentage shift out of well water into

Dependent Variable[a]	Coefficient[a]	*t* Ratio
Household Municipal Water Usage per Month (log)		
Municipal price per cubic meter (log)	−0.509*** (0.058)	−8.82
Know water tariff (1 = yes, 0 = no)	−0.562 (0.845)	−0.67
Municipal price per cubic meter (VND) (log) households knowing water tariff	−0.112 (0.119)	−1.03
Well opportunity cost price per cubic meter (log)	0.347*** (0.062)	5.59
Monthly household income (log)	0.003 (0.057)	0.06
Household size (log)	0.192 (0.178)	1.08
Well pump capacity (HP)	−0.171 (0.110)	−1.56
In-house water storage (1 = no, 0 = yes)	−0.155 (0.153)	−1.02
In-house water storage capacity (log) (m^3)	0.065 (0.155)	0.44
Farming (1 = yes, 0 = no)	−0.174 (0.252)	−0.69
Operate a home business (1 = yes, 0 = no)	0.130 (0.181)	0.72
Mills ratio	0.531* (0.30)	1.77
Constant	3.40** (1.513)	2.25
F(12, 89)	16.91	
Adjusted R square	0.35	
Household Well Water Usage per Month (log)		
Municipal price per cubic meter (log)	0.456*** (0.061)	7.48
Know water tariff (1 = yes, 0 = no)	1.533 (1.079)	1.41
Municipal price per cubic meter (VND) (log) households knowing water tariff	0.209^(0.144)	1.46
Well opportunity cost price per cubic meter (log)	−0.441*** (0.069)	−6.38
Monthly household income (log)	0.186*** (0.058)	3.24
Household size (log)	0.401 (0.289)	1.39
Motorized well pump capacity (HP)	0.633*** (0.160)	3.95
In-house water storage (1 = no, 0 = yes)	0.036 (0.227)	0.16
In-house water storage capacity (log) (m^3)	0.120 (0.164)	0.73
Farming (1 = yes, 0 = no)	0.685*** (0.291)	2.35
Operate a home business (1 = yes, 0 = no)	0.633*** (0.201)	3.15
Mills ratio	−0.063 (0.386)	−0.16
Constant	−4.786*** (1.659)	2.88
F(12, 89)	17.44	
Adjusted R square	0.39	
Observations	357	
Clusters	90	

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

piped water. Recalling that households using municipal and well water get most of their daily water from the household well, these elasticity results show at average household consumption a municipal water price increase would cause total monthly household consumption to increase as a result of the household substituting more well water consumption for foregone municipal water consumption. In contrast, increasing the well water shadow price would cause a larger volumetric shift out of well water than into municipal water, causing a net decrease in the average household's total monthly water consumption from all sources.

[30] As income increases household well water consumption also increases, significant at the 1% level. Increasing income does not appear to systematically increase municipal water consumption however. In-household water infrastructure is significant determinant of monthly household water consumption, with every one horsepower increase in pump capacity causing municipal water consumption to fall by approximately 15% and well water consumption to increase by 88%. Given that increasing pump capacity increases the convenience of drawing well water this finding makes intuitive sense.

[31] Farming and households operating a home business consume more well water than other households, but do not differ from the average in their monthly municipal water consumption. Farming households consume approximately double the amount of well water per month than an otherwise comparable household, while well water consumption by home businesses is approximately 90% greater. For farming households, these results may indicate differences in local municipal or well water quality, and also potentially some mixing of household and farm production usages. Descriptive analysis shows households operating home businesses use most additional water in their business operations.

5. Policy Implications

[32] The conditional household demand estimates impart several key messages for regional water planning in Dak Lak and for the company managing Buon Ma Thuot's municipal water supply system. The first implication of the household water demand estimates is that municipal water pricing will likely be a blunt policy tool for managing urban and periurban household water demand in Buon Ma Thuot, at least over the short term. For the minimum 40% of households in Buon Ma Thuot using municipal water exclusively, increasing the municipal water tariff would cause only a marginal reduction in total household water consumption. For the minimum 25% of households in Buon Ma Thuot that augment municipal water with well water, increasing the municipal water tariff would cause these households to increase total household water consumption from all sources, because these households will consume more household well water in substitute for municipal water. The result that households knowing the municipal water tariff have more elastic demand than households that do not know the water tariff is consistent with *Gaudin*'s [2006] finding that increasing the price information content of household water bills in the U.S. increased household price elasticity of demand by around 30%. These combined results may indicate increasing household awareness of the municipal water tariff in Buon Ma Thuot could make households connected to the municipal water system more responsive to future changes in the municipal water tariff.

[33] The second policy implication is that municipal water could feasibly be priced for full cost recovery in Buon Ma Thuot, at least over the short term. Households consuming municipal water only account for approximately 40% of all households connected to the municipal water supply system in Buon Ma Thuot, and these households had an average monthly consumption of 15.98 m^3 in 2006

Table 5. Gross Benefit and Consumer Surplus Effects of Reducing Monthly Household Water Supplies

	Monthly Household Supply Reduction						
	0.5 m^3	1.0 m^3	1.5 m^3	2.0 m^3	2.5 m^3	3.0 m^3	3.5 m^3
Municipal water tariff (VND)	2,250						
	Municipal Water Households						
Elasticity	−0.06						
Average monthly unconstrained household municipal water consumption (m^3)	16						
Constrained monthly municipal consumption (m^{-3})	15.50	15.00	14.50	14.00	13.50	13.00	12.50
Gross loss (VND)	1,488	4,058	8,582	16,700	31,580	59,471	113,037
Consumer surplus loss (VND)	363	1,808	5,207	12,200	25,955	52,721	105,162
Gross loss (VND m^{-3})	2,975	4,058	5,721	8,350	12,632	19,824	32,296
Consumer surplus loss (VND m^{-3})	725	1,808	3,471	6,100	10,382	17,574	30,046
	Municipal and Well Water Households						
Elasticity	−0.51						
Average monthly unconstrained household municipal water consumption (m^{-3})	9.12						
Constrained monthly municipal consumption loss (m^{-3})	8.62	8.12	7.62	7.12	6.62	6.12	5.62
Gross loss (VND)	1,189	2,522	4,026	5,738	7,704	9,985	12,663
Consumer surplus loss (VND)	64	272	651	1,238	2,079	3,235	4,788
Gross loss (VND m^{-3})	2,378	2,522	2,684	2,869	3,082	3,328	3,618
Consumer surplus loss (VND m^{-3})	128	272	434	619	832	1,078	1,368

(Table 1). The demand estimates in this article suggest increasing the municipal water tariff to VND 4,000 per cubic meter, which is the water supply company's estimated average supply cost, would result in households consuming municipal water only to reduce monthly water consumption to 15.25 m^3, which would result in these households' average monthly water bill increasing from VND 35,955 to VND 60,983. Assuming 20,000 households are connected to the municipal supply system suggests revenues from households connected to the municipal supply only would rise from VND 288 million to VND 488 million per month. The same tariff increase would cause households connected to the municipal system and also having household wells to increase well water consumption by around 4.9 m^3 per month, and to reduce municipal water consumption from around 9.1 to 5.5 m^3. This would result in these households' average monthly municipal water bill rising from VND 20,520 to VND 22,041. Assuming households using municipal and well water account for 25% of all households with municipal water connections in Buon Ma Thuot, the monthly revenue stream from this subgroup to the water supply company would increase from VND 103 million to VND 110 million. Importantly repricing municipal water to offset the average municipal water supply cost has a modest impact on the average household budget. Municipal water expenditure as a percentage of average monthly income for households using municipal water exclusively rises from 1.4 to 2.3%, and from 0.08 to 0.09% for households using municipal and household well water.

6. Consumer Surplus Effects From Quantity Restrictions

[34] This final section considers the welfare impacts of municipal water supply shortages on households with municipal water connections in Buon Ma Thuot. The analysis is pertinent because dry season municipal water shortages have plagued Buon Ma Thuot in recent drought years, and because Vietnam's law on water resources requires that water allocations are prioritized on efficiency and equity grounds during times of regional shortage [*National Assembly of the Socialist Republic of Vietnam*, 1998]. As long as constant elasticity does not equal −1.0, the gross value of an increase in water supply from Q_0 and Q_1 to the consumer is exactly defined by [*Gibbons*, 1986: 17]

$$V = \left(\frac{P_0 * Q_0^{\frac{1}{|\varepsilon|}}}{1 - \frac{1}{|\varepsilon|}}\right)\left(Q_0^{1-\frac{1}{|\varepsilon|}} - Q_1^{1-\frac{1}{|\varepsilon|}}\right) \tag{9}$$

where P_0 and Q_0 define the initial price quantity locus, and ε is the own price elasticity of demand estimate. Subtracting the volumetric-based water cost isolates the consumer surplus

$$S = V - [p_m(Q_0 - Q_1)] \tag{10}$$

Estimating with this approach shows consumer surplus losses caused by reducing total monthly household municipal supplies are more pronounced in households that consume municipal water only (Table 5). This is to be expected given these households' water demand is more price inelastic.

7. Conclusion

[35] This article contributes to the limited but growing literature estimating household water demand by pooling revealed and stated preference data, and also to the literature

behavior approach developed in this research can be used to recover (shadow) price elasticity of demand estimates for household water for both municipal and nonmunicipal water sources in developing countries. Compared to other stated preference approaches that could be used to estimated household water demand, the contingent behavior method this article develops has the advantage of setting household responses in the familiar behavioral context of the actual activities that consume water in the household, which may reduce potential for hypothetical response bias. When the contingent behavior approach is structured to allow for behavioral revisions based on outcome feedback, as was the case in this research, the discovered preference hypothesis [*Plott*, 1996] and its supporting literature [*Bateman et al.*, 2008] predicts increasingly valid and stable preference estimates should be forthcoming.

[36] Several limitations to this research should be noted. First, the low percentage of respondents correctly stating the municipal water tariff shows that most respondents learnt the water tariff and their preferences for water consumption as a function of price during the survey. The implication is that if a new municipal water tariff was implemented in Buon Ma Thuot, actual price elasticity of demand would likely be more inelastic than those estimated in this article [*Gaudin*, 2006]. The second limitation of the research was the artificial shadow price used for household well water. Because well water extraction costs will differ between households that use well water, using a common shadow price may have sacrificed some incentive compatibility, which implies respondents could have simply been playing by the rules of the game when estimating their household water demand.

[37] Recent enhancements to Buon Ma Thuot's municipal water supply system have caused urban and periurban households to increase municipal water consumption, thus depriving smallholder irrigators of scarce water. As rural water supply and sanitation programs are implemented in other regional centers around Dak Lak Province, this pattern of rural-urban water transfers will likely be replicated. When increasing urban water consumption diverts scarce water from other uses, opportunity costs are created and questions arise about the extent to which these transfers are justifiable on efficiency and equity grounds. The household water demand estimates in this article provide a partial basis for objectively evaluating this issue in Dak Lak Province.

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