Champion and Kathy Ludlow. Research partially supported by USDA Forest Service and the Nevada Agricultural Experiment Station.

REFERENCES

- Bergstrom, J.C. and H.K. Cordell (1991), 'An analysis of the demand for and value of outdoor recreation in the United States', *Journal of Leisure Research*, **23** (1), 67–86.
- Bowker, J.M., M.P. Miles and E.J. Randall (1997), 'A demand analysis of off-road motorized recreation', in *Expanding Marketing Horizons into the 21st Century: Proceedings of Association of Marketing Theory and Practice*, Annual Conference, Jekyll Island, Georgia, March, pp. 387–93.
- Cameron, C. and P. Trivedi (1998), *Regression Analysis of Count Data*, New York: Cambridge University Press.
- Cameron, T. and J. Englin (1997), 'Respondent experience and environmental valuation', *Journal of Environmental Economics and Management*, **33**, 296–313.
- Englin, J. and T. Cameron (1996), 'Enhancing travel cost models with multiple-scenario contingent behavior data: Poisson regression analysis with panel data', *Environmental and Resource Economics*, **7**, 133–47.
- Englin, J. and J.S. Shonkwiler (1995), 'Modeling recreation demand in the presence of unobservable travel costs: toward a travel price model', *Journal of Environmental Economics and Management*, **29**, 368–77.
- Englin, J., T. Holmes and R. Niell (2006), 'Alternative models of recreational off-highway vehicle site demand', *Environmental and Resource Economics*, **35**, 327–38.
- Gourieroux, C., A. Montfort and A. Trognon (1984), 'Pseudo maximum likelihood methods: applications to Poisson models', *Econometrica*, **52**, 701–20.
- Jakus, P.M., J.E. Keith and L. Liu (2008), 'Economic impacts of land use restrictions on OHV recreation in Utah', report for the Utah Governor's Public Lands Policy Coordination Office, Utah State University, Department of Applied Economics, Logan, UT.
- Priskin, J. (2003), 'Physical impacts of four-wheel drive related tourism and recreation in semi-arid, natural coastal environment', *Ocean and Coastal Management*, **46** (1–2), 127–55.
- Terza, J. (1998), 'Estimating count data models with endogenous switching: sample selection and endogenous treatment effects', *Journal of Econometrics*, **84**, 129–54.
- White, H. (1982), 'Maximum likelihood estimation of mis-specified models', *Econometrica*, **50**, 1–16.

11 Estimation of household water demand with merged revealed and stated preference data

Jeremy Cheesman and Jeff Bennett

INTRODUCTION

The practice of merging revealed preference (RP) and stated preference (SP) data in order to estimate demand and non-market values has gained credence in the resource and environmental economics literature since the approach was first used in Cameron (1992) and Adamowicz et al. (1994). The merging of RP and SP data provides several advantages to the researcher (Whitehead et al., 2008)

- SP data can be used to extend RP datasets to situations that have not been observed previously.
- merging SP and RP data can alleviate estimation issues of multicollinearity and endogeneity that may confound econometric estimation when only RP data is used (von Haefen and Phaneuf, 2008).
- a panel dataset is created when the RP data of an individual is merged with at least one SP observation from the same individual. This Merging generally improves estimation efficiency, all other factors constant.
- RP data can be used to identify and control response bias in SP data through the identification of whether the individual has used the same underlying preference structure in their observed behaviour, and in the formation of their stated preferences.
- Studies that have combined stated and revealed preference data come predominantly from the literature on the estimation of recreation travel demand, marketing, and the valuation of environmental services. Whitehead, et al. (2008) provide a comprehensive synthesis of this research. Resource and environmental economics literature that merges RP and SP data generally concentrates on how historical and hypothetical exogenous variations in the quantity or quality of an environmental good or service affect individual demand for that good or service (von Haefen and Phaneuf, 2008; Whitehead et al., 2000).

In this chapter, we estimate household water demand in the Central Highlands region of Vietnam using a merged RP and SP dataset. The SP data are obtained via survey using the contingent behaviour approach. The contingent behaviour method (CBM) is fundamentally similar to the contingent valuation method (CVM), but differs in the response elicited from respondents. Whereas in the CVM respondents are asked whether they would be willing to pay or accept compensation for some change in the supply or a good or service, the CBM asks respondents how they would change their behaviour if a certain state of the world occurred. That is, while the CVM elicits a value statement from the respondent, the CBM elicits a stated behavioural response in the level of use of a good or service, which can then be used to value the good or service of interest.

Here, the contingent behaviour of a household is modelled from statements of how, in response to hypothetical changes to the water price, the household would alter its water consumption in seven main usages (1) bathing and washing, (2) meal preparation, (3) drinking, (4) cleaning, (5) laundry, (6) outside (generally gardening), and (7) home business.

The merged RP/SP approach surmounts key challenges to the estimation of household water demand in developing countries. In many developing countries, households that receive municipal water supplies are charged either at a single volumetric rate, or a volumetric rate with an increasing block tariff that results in most households falling in the first or second tariff block (Whittington, 2002). In these situations, the lack of observed variation in price is a fundamental problem to the estimation of empirical household water demand functions and price elasticities. Merging RP and SP data of household water consumption overcomes this issue. Moreover, households in developing countries often consume water from multiple non-municipal sources, such as household and municipal wells, river systems and rainwater tanks. Water from these non-municipal sources is often unpriced, and is at risk of being ignored in demand estimation. Household demand substitution between water sources is an important issue of economic and water planning however, meaning a system of conditional household water demands should be estimated in this situation. The construction of shadow prices for non-priced water sources enables an understanding of the demand effects of these substitution patterns to be clarified.

To our knowledge, the study reported in this chapter is only the second to have merged RP and SP data to estimate household water demand functions and cross-price elasticities in a less developed country (LDC). Acharya and Barbier (2002) merged contingent behaviour and RP data to measure household water demand in Nigeria. Our approach differs from that of Acharya and Barbier in that we estimate household water demand

by (1) having household respondents estimate their water consumption in the seven household water usages, (2) confirming the accuracy of the household water consumption estimates against the most recent water bill of the household, and (3) using the water consumption profile of the household as an anchor from which the household could evaluate how they would practically go about altering their water consumption in response to price changes. In contrast, the approach of Acharya and Barbier required that respondents stated how much they would change total household water consumption in response to price changes, but not how they would have gone about achieving this change. Our approach is therefore more closely aligned to that of Thomas and Syme (1988), who estimated own and cross-price elasticity of household water demand in Perth, Western Australia. These authors first developed a baseline water consumption profile of each household they interviewed that concentrated on the behavioural and technical features of household water use in the bathroom, toilet, laundry, kitchen and outdoors. Then, in the contingent behaviour stage, respondents were required to identify, with the assistance of the enumerator, the specific technical and behavioural changes they would make in order to change water consumption.

The remainder of this chapter is organized as follows. First, the conceptual model of household water demand is developed in the next section, followed by the econometric specification of household water demand in section three. The fourth section deals with the empirical application, and the fifth section the results. The sixth section is devoted to a discussion of the findings, and the final section concludes.

SPECIFICATION OF THE HOUSEHOLD WATER DEMAND FUNCTION

Acharya and Barbier (2002) characterize the decision framework of water demand when the household has access to two water sources. Water from one source comes at the opportunity cost of the labour input that is required to obtain the water. Water from the second source is conventionally priced and does not require labour input. This arrangement is typical of a household that has access to piped municipal water in the house, and uses labour to draw water from an unpriced source such as a public well.

The objective of the household is to maximize its utility from water consumption, given the water sources and subject to household constraints of income and labour. The household water demand function is:

$$Q_j = Q_j(p_p, s_c, A_p, A_c, Z) \quad (11.1)$$

Q_j is the quantity of water consumed from source j , p_p is the price of purchased water, and s_c is the shadow price of the non-priced water, being the marginal opportunity cost of foregone work income. A_p, A_c are vectors of the attributes of the water by source. These attributes may include turbidity, smell, taste, delivery pressure and seasonal reliability. The vector Z defines household-specific characteristics, including income and labour capacity.

If water from the two sources is identical, that is, if $A_p = A_c$, the household maximizes utility by consuming water from both sources until the marginal rate of substitution of water purchases and water collection are equal. At this point, the marginal opportunity cost of foregone work income equals the marginal water price. The household decision framework includes two corner solutions. When the opportunity cost of foregone work income incurred by water collection always exceeds the marginal price of water, the household will only consume priced water. Moreover, when the marginal water price is always greater than the marginal opportunity cost of household labour, the household will always collect water.

ECONOMETRIC ESTIMATION OF HOUSEHOLD WATER DEMAND

We evaluate the water demands of two categories of households: those that consume water from a single source only, and those that consume water from two sources. Assume households that consume water from a single source pay a volumetric price for this water. Households that consume water from two sources take water from the priced source and from a second source with a shadow price defined by the opportunity cost of labour. Separate demand functions are estimated for each of these subgroups.

It is possible that households consuming water from two sources differ systematically, albeit in unobserved ways, from households that consume water from only one source. Consistency of econometric estimation is based on the assumption that the chance that a household belongs to one subsample is random. If the process by which a household comes to belong to one subgroup is not random, a sample selection problem arises. The parameters of an estimated econometric model that does not control for this sample selection will be biased due to violation of the Gauss-Markov assumption of zero correlation between independent variables and the error term.

Household Consumption from Multiple Sources

The two-stage estimation procedure of Heckman (1979) is used to control for potential sample selection bias. The Heckman approach involves the construction of an explanatory variable in the equation of interest that captures unobserved but systematic heterogeneity that would otherwise be included in the error term.

In the first stage of the Heckman approach, a regression for observing a positive outcome of the dependent variable is modelled with a probit model:

$$\Pr(d_i = 1) = \Pr(\mathbf{x}_i\beta < u_i) = \Phi(\mathbf{x}_i\beta) \quad (11.2)$$

where d_i is the binary dependent variable, $\mathbf{x}_i$ is a vector of household explanatory variables, β a vector of unknown coefficients to be estimated, u_i the error term, which is assumed to be distributed *iid* $N(0, \sigma^2)$, and $\Phi(\mathbf{x}_i\beta)$ is the cumulative normal distribution.

The estimated parameters of the probit model are used to calculate the inverse Mill's ratio, which is the ratio of the probability density function $\phi(\mathbf{x}_i\beta)$ over the cumulative distribution function:

$$M_i = \frac{\phi(\mathbf{x}_i\beta)}{[1 - \Phi(\mathbf{x}_i\beta)]} \quad (11.3)$$

The inverse Mill's ratio is included as an explanatory variable in the equation of interest.

Conditional Household Water Demand Functions

The demand of households that consume water from a single water source is assumed to take the functional form:

$$\ln(Q_m) = c_1 + a_1 \ln(p_m) + a_2 Z + \varepsilon_1 \quad (11.4)$$

Those households that consume water from two sources are assumed to have the conditional water demand functions:

$$\ln(Q_m) = c_2 + b_{m1} \ln(p_m) + b_{m2} \ln(s_w) + b_{m3} Z + \varepsilon_2 \quad (11.5)$$

$$\ln(Q_w) = c_3 + b_{w1} \ln(p_m) + b_{w2} \ln(s_w) + b_{w3} Z + \varepsilon_3 \quad (11.6)$$

The water price of the first source is p_m , s_w is the shadow price of water of the second source, Z describes household socio-economic characteristics,

taken to include household water supply infrastructure and the inverse Mill's ratio, and ϵ_i is the error term, which is *iid* $N(0, \sigma^2)$.

EMPIRICAL APPLICATION

Study Region

Buon Ma Thuot (BMT) is the capital city of Dak Lak Province in the Central Highlands of Vietnam, and is located in the middle of the Dak Lak Plateau. The Dak Lak Plateau is characterized by intensive agricultural production, primarily of Robusta coffee destined for international export markets. Sustained growth in the regional population and in intensive agriculture has contributed towards the region facing increasingly severe dry season water shortages. The effective management of the scarce water resources of the plateau is therefore of key importance to being able to sustain economic growth of the region over the long run.

Households in BMT that are connected to the municipal water system pay a non-tiered tariff of VND2250 per cubic metre of water supplied. This tariff falls below the long run marginal supply cost of municipal water, which is estimated to be around VND4000 per cubic metre. Household consumption of municipal water is metered, and households receive monthly water bills.

Many households connected to the municipal water supply system also draw water for household usage from at least one other source, typically a private household well, or from water vendors. Prior to this study, little was known about household water consumption external to the municipal supply system, nor why households chose to consume water from sources other than the municipal system. These water substitution strategies of households carry important implications for economic and water planning in the Dak Lak Plateau.

Household Survey Procedure

The merged RP and SP dataset was obtained via a household survey. The RP data were the observed water consumptions of households, taken from monthly household water bills. The SP data were obtained using a CBM approach in which households were asked how they would alter their monthly water consumptions in seven household usages following the introduction of a hypothetical (shadow) water price.

The objective of the first stage of the survey interview was to develop the household profile of water consumption behaviour, and technology used to

deliver and consume water in the household for seven main usages: bathing and washing, meal preparation, drinking, cleaning, laundry, outside (mainly gardening) and home business. To do this, the enumerator walked through the household and identified with the respondents: (1) where activities that consumed water occurred; (2) the technology used in the water consuming activity (if any); and (3) where the water came from. Following this initial identification, the enumerator worked with respondents to estimate the amount of water consumed in each of the seven main household usages during a normal day. As different household members are generally responsible for specific water using activities, both the male and female household heads were asked to participate in the survey when available. Having both household heads responding may reduce the potential for strategic behaviour, because respondents audited each other and there was open discussion on points of difference. The household members estimated their daily water consumption mainly by demonstration. For water usages that were not daily, weekly consumption figures were estimated.

After the daily or weekly water consumption of the household was estimated in the seven usages, the enumerator extrapolated these data to estimate the monthly water consumption and expenditure profile of the household, by water source and by usage. This was compared to the most recent water bill on hand to check how accurately respondents had estimated their household water consumption.

The same procedure was followed to calculate the monthly cost of private well water by household usage. The opportunity cost of household well water was assumed to be VND450 per cubic metre, which was the average opportunity cost of households that participated in the pre-testing stage. While it would have been preferable to calculate and use household specific shadow prices of well water, pre-testing indicated this approach was prohibitively time consuming, caused distraction and often resulted in the enumerators estimating an incorrect shadow price.

After the enumerator confirmed that the respondents understood their monthly water cost by the seven household usages by source, this water usage and expenditure profile was used as the anchoring point for the CBM scenarios. In the CBM scenarios, respondents were presented with a hypothetical change in either the price of municipal or well water, while the price of water from the second source was held constant. Each household received one price below the VND2250 tariff (VND500, VND1000 or VND1750) and one higher hypothetical price (VND5000, VND7500, VND10000, VND15000 or VND25000). The same approach was followed to obtain monthly well water consumption contingent on hypothetical well water shadow prices. Hypothetical prices were VND100, VND250, VND1000, VND1500, VND2000, VND2500, VND3000, VND4500, or VND7500.

Using the hypothetical price, the enumerator first calculated the new total cost of monthly household water under the assumption that monthly water consumption did not change. This total water cost to the household was separated into the cost components of the seven household usages. The approach enabled respondents to understand how their total monthly water expenditure was distributed between the seven usages by source. Respondents were then asked whether they would alter their household water consumption in any way as a result of their new water budget. Households that stated they would change their water consumption were asked to describe or show the enumerator how they would change their water consumption patterns across the seven usages. While respondents could employ behavioural, technical or structural means to alter their water consumption, most respondents focused on short-term behavioural adjustments. These behavioural adjustments generally involved changing the amount of water consumed, or the substitution of water from one source to the second. After respondents had revised their household water consumption, the enumerator recalculated the water consumption and expenditure profile of the household. Respondents who were satisfied with the profile proceeded to the next scenario, while dissatisfied households iterated the process until they were satisfied.

The household survey was undertaken in mid-2006 and obtained 291 usable responses.

RESULTS, DISCUSSION AND POLICY IMPLICATIONS

Household Profiles

Table 11.1 summarizes key statistics of the households surveyed. Approximately 55 per cent of the households participating in the survey consumed municipal water only. A further 32 per cent consumed municipal water and household well water, and the remainder consumed municipal water and water from various other sources. The daily per capita consumption of households that consumed only municipal water was 120 litres. Households that consumed municipal and household well water consumed around 70 litres of municipal water per capita per day. Of households consuming municipal water solely, the municipal water bill accounted for less than 1.5 per cent of monthly household income; in the case of households that drew water from two sources the figure was 0.8 per cent.

Almost nine out of ten households had some form of in-house water

Table 11.1 Household descriptive statistics

Variable	Unit	Obs.	Mean	SD	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
Household income	VND Mil	291	3.29	2.27	0.25	20.00
Operate a home business	Yes = 1	291	0.28	—	0	1
Household water consumption						
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 per cent of household income	%	119	1.37	1.67	0.04	17.33
Municipal water and private well	Yes = 1	291	0.32	—	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 per cent of household income	%	92	0.81	0.75	0.05	4.05
Water storage tank situation						
Have in house water storage tank	Yes = 1	257	0.81	—	0	1
Average storage tank capacity	m ³	208	2.41	1.86	0	16
Household knowledge of municipal water tariff						
Municipal water tariff correctly described	Yes = 1	291	0.15	—	0	1

storage infrastructure, mainly to stock against intermittent water supply shortages. Cement water storage tanks were the most prevalent form of storage infrastructure, being installed in eight of every ten households surveyed. The average storage capacity of the cement storage tanks was 2.4 cubic metres. This is a sufficient storage capacity to supply the average household with 4.5 days of water at 120 litres per capita per day. Approximately 85 per cent of those households that used household wells drew water using motorized pumps. Notably, only 15 per cent of households surveyed knew the municipal water tariff.

More detailed descriptive analyses are provided in Cheesman et al. (2007).

Accuracy of Households' Own Estimates of Water Consumption

The accuracy of the econometric estimates of household water demand rely on the ability of the households surveyed to estimate accurately their water consumption, and then estimate how household water consumption would change in response to the hypothetical price changes. To evaluate the ability of households to estimate their existing household water consumption, pair-wise correlations were constructed of the actual monthly municipal water consumption of the household from the most recent municipal water bill on hand, and the household municipal water consumption that was estimated by the household with assistance of the enumerator.

The pair-wise correlation of these covariates for households that only consumed municipal water was 0.86. The pair-wise correlation of the covariates for households that consumed municipal and household well water was 0.93. Both correlations were significant at the 1 per cent level. These pair-wise correlations suggest that the participating households were able to estimate their household water consumption with reasonable accuracy. Further, the accuracy of the estimates suggest that households drawing well water are likely to consume around 100 litres of household well water per capita per day. These estimates suggest that those households consuming both well and municipal water had a combined per capita consumption of 170 litres per day, on average.

Estimates of Household Water Demand

Consistency of RP and SP preferences

A dummy variable approach was used to test the assumption that households used the same underlying preference structure in the formation of their RPs and SPs. This involved the inclusion of a dummy variable in the system of demand equations to test the null hypothesis of the equivalence of the RP and SP data. Equivalence was not rejected in any of the demand equations.

Water demand of households using municipal water only

The water demand of those households that solely consumed municipal water was estimated by random effects generalized least squares. The balanced panel dataset contained 390 observations, comprising two contingent behaviour responses and one revealed preference

response per each of the 130 households that consumed only municipal water.¹

Several functional forms were evaluated and only the best fitting model is reported here:

$$\begin{aligned} \ln(Q_{m,i,t}) = & c_1 + a_1 \ln(p_{m,i,t}) + a_2 D_{know_{m,i}} + a_3 \ln(p_{know_{m,i,t}}) + a_4 \ln(inc_i) \\ & + a_5 \ln(hhsize_i) + a_6 D_{store,i} + a_7 \ln(store_i) \\ & + a_8 farm_i + a_9 own_i + a_{10} mills_i + w_{i,t} \end{aligned} \quad (11.7)$$

(*i*) is the household observation number, (*t*) the elicited observation, $\ln$ denotes logarithms to base e, and Q_m is the dependent variable, which is the monthly municipal water consumption of the household, measured in cubic metres. Variables used to explain household water consumption are the municipal water price (p_m), a dummy variable (D_{know_m}) that differentiated those respondents who knew the municipal water price and those respondents who did not, an interaction variable that measured the partial effect of knowing the municipal water tariff on demand elasticity (p_{know_m}), income (inc), household size ($hhsize$), which we measured as the number of people who lived in the household for more than five months each year in order to account for itinerant labour, a dummy variable to differentiate between households with in-household water storage (D_{store}) from those who did not; household water storage capacity, measured in cubic metres ($store$), dummy variables to distinguish between farming and non-farming households ($farm$), and those households with home businesses (own), and the inverse Mill's ratio calculated from the probit estimate ($mills$) (Table 11.2).

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 $iid N(0, \sigma^2)$. The approach in Battese (1997) was used to code the dummy and interaction variables to identify those respondents who knew the municipal water tariff and their marginal price elasticity, and also for the subgroup of households with in-household water storage and their storage capacity. The Battese approach overcomes potential estimation bias that may result from assigning small values to observations with a value of zero prior to these data being transformed to natural logarithms.

Water storage infrastructure was assumed to be exogenous to present water consumption as the majority of households had water storage in place prior to a substantial upgrade to the municipal supply system in 2003.

Table 11.2 Household well status, probit model results

	Coefficient	z-ratio
Dependent variable: probability of having a household well		
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 in cubic metres	-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 (0.207)	1.19
Constant	-0.161 (0.284)	-0.57
Log likelihood	-138.890***	
Likelihood ratio chi2(5)	19.89	
Pseudo R ²	0.07	
Percentage correct predictions (overall)	65	
Observations	220	

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 11.3 summarizes the estimated municipal water demand function. A Hausman test confirmed the orthogonality conditions imposed by the random effects estimator were not violated. A Breusch-Pagan Lagrange multiplier test rejected the null hypothesis that the variance of u_i was equal to zero, and thereby demonstrated that significant individual effects existed in the demand equation.

Own price elasticity of household water consumption was -0.06, significant at the 1 per cent level. Those households that knew the municipal water tariff had marginally more elastic demand for water, at -0.08. Income elasticity is significant at the 10 per cent level, and shows that a 10 per cent increase in monthly household income increases consumption of household water by 1.4 per cent, on average. Monthly household municipal water consumption increases as the number of household residents increases, at a rate of around 50 per cent per individual.

The significant dummy variable for in-household storage shows that households with water storage infrastructure consumed more water than households without storage, irrespective of the total storage capacity.

Table 11.3 Random effects water demand estimates for households using municipal water only

	Coefficient	z-ratio
Dependent variable: log of total municipal water usage per month, m ³		
Municipal price per cubic meter (VND) (log)	-0.059*** (0.005)	-12.71
Know water tariff (1 = No, Yes = 0)	-0.096 (0.134)	-0.72
Municipal price per cubic metre (VND) (log) – households knowing water tariff	-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 Yes = 0)	-0.144^ (0.092)	-1.57
In-house water storage capacity in cubic metres (log)	0.110** (0.051)	2.17
Farming (1 = Yes, No = 0)	-0.016 (0.153)	-0.10
Operate a home business (1 = Yes, No = 0)	0.101 (0.079)	1.28
Mills ratio	0.086 (0.150)	0.57
Constant	0.161 (1.139)	0.14
Wald chi ² (9)	294.24	
Adjusted R-square	0.43	
Observations	390	
Groups	130	
Hausman test for random effects		
Ho: difference in coefficients not systematic.		
chi ² (2)	0.10	
Prob > chi ²	0.95	
Breusch and Pagan Lagrangian multiplier test for random effects:		
H0: Var(u) = 0		
chi ² (1) =	349.19	
Prob > chi ²	0.00	

Notes: ^, *, ** and *** denote statistical significance at 15, 10, 5 and 1 per cent level respectively. Numbers in parentheses are asymptotic standard errors.

Moreover, the significant elasticity estimate of water storage capacity shows that as the water storage capacity of the household increases, so does municipal water consumption. Estimated coefficients of the variables for operating a home business, operating a farm and the inverse Mills ratio are insignificant. The lack of significance of the inverse Mill's ratio suggests household well status does not suffer from selection bias.

Conditional water demand of households using municipal and well water

The conditional water demands of the 90 households that consumed municipal and well water were estimated with an unbalanced panel dataset of 357 observations. The conditional household demand functions were estimated using seemingly unrelated estimation (SUE). Seemingly unrelated estimation combines the parameter estimates, the variance and covariance matrices of the separately estimated municipal and well water demand equations into a robust single parameter-vector and simultaneous variance covariance matrix. Estimation using yields the same coefficients as seemingly unrelated regression (SUR). Seemingly unrelated estimation is less efficient than SUR, but is robust to cross-equation correlation and between group heteroskedasticity, which is likely present in this dataset.

Household demand for municipal and well water was defined to be a function of the same explanatory covariates:

$$\ln(Q_{j,i,t}) = c_j + b_{j1} \ln(p_{m,i,t}) + b_{j2} D_{know,i} + b_{j3} \ln(p_{knowm,i,t}) + b_{j4} \ln(s_{w,i,t}) \\ + b_{j5} \ln(inc_i) + b_{j6} \ln(hhsize_i) + b_{j7} pc_i + b_{j8} D_{store,i} \\ + b_{j9} \ln(store_i) + b_{j10} farm_i + b_{j11} own_i + b_{j12} mills_i + e_{j,i,t} \quad (11.8)$$

$s_{w,i,t}$ is the shadow price of household well water, pc denotes the horsepower of the household well pump. The other variables of the equation have already been defined. We assumed that water storage infrastructure and pump capacity were exogenous in the demand system for the same reasons cited as those households that solely consumed municipal water.

Table 11.4 presents the estimation results of the conditional household demand functions. The estimated own price elasticity of municipal water is -0.51, and the own price elasticity of well water -0.44. Both estimates are significant at the 1 per cent level. The cross price elasticity of municipal water is 0.49, and 0.34 for household well water, significant at the 1 per cent level. The result confirms that municipal and well water are substitutes.

Tests of the cross-equation equality of the own and cross-price elasticity coefficients show that the ratio of these elasticities for municipal water were statistically equal to -1. In other words, when a household reduces municipal water consumption by a given percentage in response to an

Table 11.4 *Seemingly unrelated water demand estimates for households using municipal and private well water*

	Coefficient	t-ratio
Dependent variable: household municipal water usage per month (log)		
Municipal price per cubic metre (log)	-0.509*** (0.058)	-8.82
Know water tariff (1 = Yes, No = 0)	-0.562 (0.845)	-0.67
Municipal price per cubic metre (VND) (log) – households knowing water tariff	-0.112 (0.119)	-1.03
Well opportunity cost price per cubic metre (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 Yes = 0)	-0.155 (0.153)	-1.02
In-house water storage capacity in cubic metres (log)	0.065 (0.155)	0.44
Farming (1 = Yes, No = 0)	-0.174 (0.252)	-0.69
Operate a home business (1 = Yes, No = 0)	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	
Dependent variable: household well water usage per month (log)		
Municipal price per cubic metre (log)	0.456*** (0.061)	7.48
Know water tariff (1 = Yes, No = 0)	1.533 (1.079)	1.41
Municipal price per cubic metre (VND) (log) – households knowing water tariff	0.209^ (0.144)	1.46
Well opportunity cost price per cubic metre (log)	-0.441*** (0.069)	-6.38
Monthly household income (log)	0.186*** (0.058)	3.24

Table 11.4 (continued)

	Coefficient	t-ratio
Household size (log)	0.401 (0.289)	1.39
Motorised well pump capacity (HP)	0.633*** (0.160)	3.95
In-house water storage (1 = No, Yes = 0)	0.036 (0.227)	0.16
In-house water storage capacity in cubic metres (log)	0.120 (0.164)	0.73
Farming (1 = Yes, No = 0)	0.685*** (0.291)	2.35
Operate a home business (1 = Yes, No = 0)	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	

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

increase in the price of municipal water, they substitute consumption by increasing well water consumption by an equal percentage. On the other hand, an increase in the shadow price of household well water was found to result in a larger percentage shift out of well water than was substituted into municipal water.

Household income elasticity of well water consumption was 0.19, significant at the 1 per cent level. The income elasticity of municipal water consumption was insignificant.

The estimates suggest that pump capacity is the main infrastructure determinant of the volume of well versus municipal water consumed. Each additional horsepower of capacity in the household well pump causes municipal water consumption to fall by approximately 15 per cent, and well water consumption to increase by 88 per cent. Household water storage capacity was not a significant determinant of the monthly consumption of municipal or well water of the household.

Households whose main occupation was farming, and those households who operated a home business, consume a larger quantity of well water than otherwise similar households, but have the same consumption levels of municipal water as otherwise comparable households. Farming households consume approximately double the amount of well water per month than an otherwise comparable household, while the well water consumption of home businesses is approximately 90 per cent greater than an otherwise identical household. 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.

DISCUSSION

Compared to estimates of household water demand in LDCs from other studies, in this study the own price elasticity of households that only consumed municipal water is highly inelastic. In their review of the literature on household water demand in LDCs, Nauges and Whittington (2008) concluded that most estimates of own price elasticity of water from private connections fell within a range of -0.3 to -0.6, which is consistent with own price elasticities of household water demand observed in industrialized countries. In comparison, the own price elasticity of households that consumed only piped water in this study was -0.06. The own and cross-price elasticities of the households in our study that drew municipal and well water align with elasticity estimates of earlier studies. While the elasticity estimates are consistent, the substitution effects of the cross-price elasticities means that these households also did not reduce total household water consumption to any great degree in response to price changes. Rather, they simply substituted water from one source for the other.

However, the extent to which cross-LDC comparisons of household water demand can be relied upon to make conclusions about the veracity and implications of a particular set of observed price elasticity estimates is limited. It is reasonable to assume in the cross-country comparison of the water demands of households in industrialized nations that municipal water supplies are relatively homogenous in terms of potability, supply reliability, delivery pressure, and so on. The same assumption cannot be made of piped water supplies in LDCs. As a result, it is unclear whether estimates of household water demand across LDCs are for directly comparable goods. Moreover, households in developed economies are typically homogenous in the sense that they consume the bulk of their water

from a municipal source only, and would not substitute with other sources in response to price changes. The same cannot be assumed for households in LDCs. The possibility that household water demand studies in LDCs do not identify all water source substitutions in their demand specification also exists.

Households in our survey that used municipal water only consumed approximately 120 litres per capita per day (l/c/d) on average, and households consuming municipal water and well water around 190 l/c/d. These quantities are well above the 20 l/c/d minimum water requirement for human hygiene set by the WHO and UNICEF (WHO/UNICEF, 2000). The daily per capita consumption of households is also near or above estimates of the per capita household water requirement for economic and sustainable development, which is around 135 l/c/d (Chenoweth, 2008). In other words, the observed inelasticity of demand of households in our study cannot be attributed to households already being very low per capita water users. Thus, some other factor must be at play.

One potential reason for the relatively inelastic demand of households that consumed municipal water only is the small impact that the raising of municipal water prices had on the total household budget. The hypothetical municipal water prices used in the survey were 2.2, 3.1, 4.4, 6.7 and 11 times the existing tariff of VND2250. The average income of households in the survey that used municipal water only was 20 per cent higher than that of all other households (VND3.6 million versus VND2.9 million). The average of monthly water consumption of households using municipal water only was 15.98 cubic metres, and the own price elasticity -0.06 . Adjusting the total monthly household water consumption of the average household for own price elasticity means that for the price scenarios considered the water bill of households that consumed municipal water only is always less than 4 per cent of household income. Thus, one potential explanation is that the hypothetical price changes of the contingent behaviour scenarios may not have caused a sufficient impact on the household budget to induce a substantial change in consumption behaviour.

Nevertheless, the highly inelastic demand of households in this survey, especially those consuming municipal water only, is deserving of further consideration. Several further paths of research exist. These include the estimation of separate arc elasticities between the RP/SP price points, estimation of the household water demand relationship using a more flexible functional specification, and estimation of the own and cross-price elasticities of specific household water usages.

Our estimates of household water demand in BMT have ramifications for the water supply planners of BMT, and for regional water management by implication. The first ramification is that the pricing of municipal

water in BMT cannot be used to manage household water consumption, at least over the short term. For the minimum 40 per cent of households in BMT that use municipal water exclusively, increases in the municipal water tariff over the range considered in this research appear to have little impact on household water consumption. Moreover, for the minimum 25 per cent of households in BMT that augment municipal water with well water, increasing the municipal water tariff would cause these households to substitute water consumption between sources, but not reduce total consumption. Second, the result observed that households knowing the municipal water tariff have more elastic demand than households that do not know the water tariff is consistent with that of Gaudin (2006), who found that increases in the price information content of domestic water bills increased own price elasticity of demand by 30 per cent. These results, in combination with the fact that 85 per cent of respondent households were unaware of the domestic water tariff, suggests that one pathway to strengthen the ability of water authorities to effect demand management would be to make households more aware of the price of municipal water.

CONCLUSION

This research contributes to the limited but growing body of studies that have merged stated preference and revealed preference data to estimate household water demand. The chapter also contributes to the growing body of literature on the estimation of household water demand in LDCs. The results of the study suggest that the novel household water activity budget approach used to estimate household water consumption, and then to predict how households would alter their water consumption behaviour in response to hypothetical changes in the water price, can be used to estimate the (shadow) price elasticity of household water demand from municipal and non-municipal supply sources. One strength of the contingent behaviour method is that household responses to hypothetical changes in the water price were anchored in the respondents' understanding of how the household actually used water in various activities. This approach may reduce the potential for hypothetical response bias.

Limitations of the research approach should be noted. The low percentage of respondents who knew the municipal water tariff a priori shows that most respondents learnt the water tariff and their preferences for water consumption as a function of price from the survey. By implication, if this situation did not change and a new municipal water tariff was implemented in BMT, then the majority of households would not alter water consumption. The artifice of the shadow price of household well water

used in the study is a second limitation. Because the cost of household well water will differ between households, the use of a common shadow price may have sacrificed some incentive compatibility. If this is the case, then respondents could have simply been playing by the rules of the game in the estimation of their demand for household well water.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the Australian Center for International Agricultural Research (ACIAR) for project funding. The authors also thank, without implication, Céline Nauges, Truong Dang Thuy and Vo Duc Hoang Vu, Tran Ngoc Kham, and the graduate students at Ho Chi Minh City University of Economics and Tay Nguyen University who were survey enumerators.

NOTE

1. Comparison of the household descriptive statistics and the results of the contingent behaviour scenarios revealed that a number of households who reported not having access to a private well stated that they would draw water from a private household well if the municipal water price were to increase. In the estimation of water demand, households that stated they would use a household well in at least one of the contingent behaviour scenarios were categorized as being dual access households. Moreover, households that only drew from the municipal source in the contingent behaviour scenarios were categorized as single (municipal) source households. The categorization resulted in a subgroup of 133 households using municipal water exclusively, and a subgroup of 92 households using municipal and well water. The remaining 66 households that drew water from other secondary sources were excluded from the demand analysis due to small subgroup numbers. Removal of influential outlier observations reduced the municipal water subgroup to 130 observations, and the dual source subgroup to 90 observations.

REFERENCES

- Acharya, Gayatri and Edward Barbier (2002), 'Using domestic water analysis to value groundwater recharge in the Hadejia-Jama'are Floodplain, Northern Nigeria', *American Journal of Agricultural Economics*, **84** (2), 415–26.
- Adamowicz, Wiktor, Jordan Louviere and Michael Williams (1994), 'Combining revealed and stated preference methods for valuing environmental amenities', *Journal of Environmental Economics and Management*, **26**, 271–92.
- Battese, George E. (1997), 'A note on the estimation of Cobb-Douglas production functions when some explanatory variables have zero values', *Journal of Agricultural Economics*, **48** (2), 250–52.
- Cameron, Trudy (1992), 'Combining contingent valuation and travel cost data for the valuation of nonmarket goods', *Land Economics*, **68**, 302–17.

- Cheesman, Jeremy, Tran Vo Hung Son, Tuong Dang Thuy, Vo Duc Hoang Vu and Jeff W. Bennett (2007), 'The marginal economic value of household water in Buon Ma Thuot, Viet Nam', *Managing Groundwater Access in the Central Highlands of Viet Nam*, Canberra: Australian National University.
- Chenoweth, Jonathan (2008), 'Minimum water requirement for social and economic development', *Desalination*, **229** (1–3), 245.
- Gaudin, S. (2006), 'Effect of price information on residential water demand', *Applied Economics*, **38** (4), 383–93.
- Heckman, James R. (1979), 'Sample selection bias as a specification error', *Econometrica*, **47** (1), 153–61.
- Nauges, Céline and Dale Whittington (2008), 'Estimation of water demand in developing countries: an overview', working Papers 08.20.264, LERNA, University of Toulouse.
- Thomas, J.F. and G.J. Syme (1988), 'Estimating residential price elasticity of demand for water: a contingent valuation approach', *Water Resources Research*, **24**, 1847–57.
- Von Haefen, Roger H. and Daniel J. Phaneuf (2008), 'Identifying demand parameters in the presence of unobservables: a combined revealed and stated preference approach', *Journal of Environmental Economics and Management*, **56** (1), 19.
- Whitehead, John C., Subhrendu K. Pattanayak, George Van Houtven and Brett R. Gelso (2008), 'Combining revealed and stated preference data to estimate the nonmarket value of ecological services: an assessment of the state of the science', *Journal of Economic Surveys*, **22** (5), 872–908.
- Whitehead, John C., Timothy C. Habb and Jikun Huang (2000), 'Measuring recreation benefits of quality improvements with revealed and stated behavior data', *Resource and Energy Economics*, **22**, 339–54.
- Whittington, Dale (2002), *Municipal Water Pricing and Tariff Design: A Reform Agenda for Cities in Developing Countries*, Washington DC: Resources for the Future.
- World Health Organization/United Nations Children's Fund (WHO/UNICEF) (2000), 'Joint monitoring programme for water supply and sanitation, global water supply and sanitation assessment 2000 report', Washington, DC.