Socioeconomic study of domestic water consumption in the Federal District, Brazil

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ABSTRACT: Based on the hypothesis that variables such as the cost of water, family income, household size and building typology affect the way water is consumed, this paper describes the results obtained from fieldwork and discusses domestic water consumption for different residential building types of high, mid-high, mid-low and low income dwellings in the Federal District. An econometric model and correlation analysis, using primary data collected in fieldwork, have been estimated for a water demand function in order to understand what lies behind domestic water consumption in the Federal District. The correlation analysis carried out shows a good relationship between indoor water consumption and built area (0.63), dwelling income (0.49), and number of residents (0.37). Estimated water consumption function has shown a relationship between dwelling income and built area. Through multiple regression, indoor and outdoor water consumption functions were estimated for the Federal District. The coefficient of cost of water presented a positive relationship showing that water demand is inelastic to water price due to the fact that water tariff is low, there is no substitute for water, and water tariff represents a small fraction of household income. This study has shown that domestic water consumption increases proportionally to the increase in household income and that it is a function of income, cost of water, household size and typological characteristics of built area.

Keywords *Water Demand, Domestic Water Consumption, Correlation Analysis, Econometric Model*

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1. INTRODUCTION

A great deal of economic research has been carried out over pricing policies as a mechanism for managing domestic water consumption. The efficiency of pricing policies is dependent upon the price elasticity of domestic water consumption, where, the higher the elasticity, the more effective the policies are (Arbués, Villanúa et al. 2010). Empirical studies indicate that consumer-response to changes in the cost of water is correlated with a series of explanatory variables affecting domestic water demand (Espey, Espey et al. 1997). Numerous econometric models have been estimated by making use of income as an independent variable of water demand function in order to identify adequate price rate structures for water charging (i.e. Billings and Agthe 1980; Agthe and Billings 1987; Niewswiadomy and Molina 1989; Hewitt and Hanemann 1995; Dalhuisen, Florax et al. 2003).

Generally, income is a measure of purchase power and is commonly associated with living standards and level of education. Income can have an effect over the perception of water cost. High income households might not be as responsive to water pricing as low income households (Agthe and Billings 1987). Worthington and Hoffman (2008) point out that estimates of income elasticity in the literature indicate that domestic water consumption is income inelastic and small in magnitude. Although results are consistent with income inelasticity, sample bias might have a role to play. The authors argue that most studies were carried out in populations with similar household income, and that domestic water demand might prove to be income-elastic in an income-diverse situation, such as those found in developing economies.

If domestic water consumption is measured at the household level, the number of residents should have a positive association with water use, since occupancy has a direct influence on water consumption. Studies demonstrate that household size is correlated with domestic water consumption (Barrett and Wallace 2009; Schleich and Hillenbrand 2009; i.e. Arbués, Villanúa et al. 2010). It is expected that, the larger the number of residents in a household, the bigger the consumption will be. However, it has been found that the increase in domestic water consumption is less than proportional to the increase in household size (Arbués, García-Valiñas et al. 2003; Worthington and Hoffman 2008). Research focused on household size and domestic water consumption indicated that domestic water consumption per capita is inversely related to the number of residents in a dwelling (Arbués, Villanúa et al. 2010). Such aggregated statistical analysis of household size and domestic water consumption per capita suggests that the greater the number of residents in a dwelling, the lower the rate of per capita consumption. This indicates that domestic water consumption is not only associated with the number of persons in a household, but also with other communal uses (i.e. irrigation, cleaning, floor-washing, swimming pool, etc.).

A series of studies indicate that domestic water consumption varies according to residential building typology (i.e. Thackray, Cocker et al. 1978; Russac, Rushton et al. 1991; Loh and Coghlan 2003; Troy and Holloway 2004; Zhang and Brown 2005; Fox, McIntosh et al. 2009). According to Fox et al. (2009), a significant relationship between physical property characteristics and domestic water consumption can be found. An investigation carried out by Russac et al. (1991) found that water consumption was higher in detached houses and lower in flats. A study focusing on indoor and outdoor domestic water usage for single and

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multi-storey and dwellings found that multi-storey dwellings used less water than single residential dwellings (Loh and Coghlan 2003). This might be attributed to the typological characteristics of residential multi-storey buildings, since flat dwellings contain communal garden areas, and therefore can have a lower water consumption rate on outdoor activities than house dwellings with individual gardens.

Clearly, domestic water consumption can be affected by a series of variables. These explanations can vary from place-to-place leading to differences in patterns of water consumption. Countries with different national income and built-types are most likely to present distinct patterns of domestic water consumption. With these issues in mind, this study sets out to understand what lies behind domestic water consumption in the Federal District, Brazil, based on the hypothesis that variables such as the cost of water, family income, household size and building typology affect domestic water consumption.

2. METHODOLOGICAL APPROACH

The approach to assess domestic water consumption was through the use of statistically representative sites and residential typologies for different income ranges. As a starting point, this investigation set out to understand and compare domestic water consumption by cross referencing geo-demographic and socio-economic indicators as well as secondary data of dwelling typology in the Federal District to point out statistically representative regions for analysis. As a result, eight Administrative Regions (ARs) in the Federal District were selected for primary data collection. Two ARs were selected according to the country's four main income groups following the Brazilian Institute for Geography and Statistics standards for household income subdivision in minimum wages (m.w.): i) low income – 1 to 5 m.w.; ii) mid-low income – 5 to 10 m.w.; iii) mid-high income – 10 to 20 m.w.; and iv) high income – above 20 m.w.

Lago Norte and *Lago Sul* ARs were selected for analysis due to their similar dwelling typology (houses ranging from 220 m^2 to 400 m^2), highest water consumption rates (12.9 – 20.4 m^3/month/person), and average monthly income equivalent to ~21.7 and ~26.5 minimum wage (m.w.) respectively. *Brasília* and *Águas Claras* ARs were selected for analysis because they contain the largest number of flats in the Federal District (from 60 m^2 to 120 m^2) with household monthly income of ~12.05 m.w. *Taguatinga* and *Candangolândia* ARs were selected mainly because of their dominant dwelling typology of houses ranging between 60 m^2 and 120 m^2 and because their water consumption rate represent the average water consumption per capita of the mid-low income group. *Celiândia* and *Samambaia* contained the highest number of habitants and are therefore capable of providing a significant representative sample for analysis, with a dominant house dwelling typology below 60 m^2 and a low income of ~2.41 m.w. ~2.89 m.w. respectively.

In order to explore the relationship between domestic water consumption and cost of water, family income, household size and residential dwelling typology this study made use of face-to-face questionnaire survey over a stratified random sample size of 481 dwellings. The face-to-face questionnaires were applied to houses and flats in order to collect quantitative data on indoor water consumption, outdoor water consumption, number of residents, income, cost of water, built area and garden/yard area. For monthly water expenses, residents were asked to consult a recent water bill. In Brazil, water bills present data of

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monthly dwelling water consumption for the past 12 months as well as information on water and sewage block-rate tariffs. In order to estimate monthly outdoor water consumption, residents were asked about their water-using habits of external faucets, after their flow rates were measured.

A correlation analysis between a series of variables related to domestic water consumption, household composition and dwelling characteristics was performed and their relationship measured with Pearson's coefficient. Coefficients which indicated a predictive relationship between variables of indoor and outdoor water consumption were reported and used in a regression analysis to estimate the domestic water consumption function. Multiple regression allowed the development of indoor and outdoor water consumption models generating a prediction tool for domestic water consumption based on a set of explanatory variables.

3. RESULTS

3.1 Income

Residents were asked to inform their dwelling's gross income. Table 1 summarizes findings. In total, 12% of the respondents did not know or refused to provide the dwelling's gross monthly income. From those who did answer, 2% of the dwellings were rated as poor (less than R$ 800 monthly), 23% presented a low income (between R$800 and R$4,000 per month), 20% had a mid-low income (between R$4,001 and R$8,000), 18% with mid-high income (between R$8,001 and R$16,000) and 26% of the dwellings presented a high income (above R$16,000 per month).

Table 1. Average income per administrative regions

Administrative Regions	Mean Income per Dwelling			Mean Income per Capita		
	m.w.	R$/month	Std. Dev.	m.w.	R$/month	Std. Dev.
Lago Norte / Lago Sul	27.45	21,630	1,835	6.86	5,405	1,261
Brasília / Águas Claras	20.28	15,980	3,405	7.46	5,878	2,012
Taguatinga / Candangolândia	11.78	9,283	3,117	3.19	2,514	1,314
Ceilândia / Samambaia	4,35	3,428	2,106	2.27	1,788	1,977

m.w.: monthly minimum wage

3.2 Household size

It was observed that the majority of high income dwellings had maids and, in some cases, gardeners or housekeepers, who had a place to stay in the household, and therefore, these workers were considered as residents of the dwelling due to the fact that they are key-consumers of water. Mid-high income dwellings had maids that would come to work on a daily basis and return to their own homes at evening or, would either work 1 to 3 days during the week. In this case, they were not considered as residents. Few mid-low income dwellings had maids working at the home and no low income dwelling had a maid.

High income dwellings (*Lago Norte* and *Lago Sul*), mid-low income dwellings (*Taguatinga* and *Candangolândia*), and low income dwellings (*Ceilândia* and *Samambaia*) presented an average of 5 residents per dwelling, while mid-high income dwellings (*Brasília* and *Águas Claras*) had the lowest number of residents, an average 3 residents per dwelling. Taking all the income groups together, the average was equal to 4.3 residents per dwelling in the Federal District.

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3.3 Residential typology

Lago Norte and *Lago Sul* dwellings were either ground floor bungalow houses (65%) or one story detached houses (35%) with a mean built area of 427m². Due to strict local land use planning laws, the constructible area within a mean 1,738m² plots are limited, and therefore contain mean roof projections of 373m² and extensive vegetated gardens of 1,364m². Almost every home had an extension with a barbeque area next to a swimming pool (mean volume of 53m³).

All of *Brasília* and *Águas Claras'* dwellings were flats, with an mean built area of 91m². Having different urban planning laws, *Brasília* and *Águas Claras* residential building blocks differed in size and built form. Due to *Brasília's* urban planning, the residential building stock consisted of dominantly horizontal high rise buildings with 4 or 6 storey high rise buildings. With a mean roof area of 1,095m², the number of flats per floor varied from 8 to 16. *Águas Claras'* residential building stock on the other hand, had a dominant vertically shaped high rise buildings ranging from 12 to 25 storey high. Most residential buildings contained 4 flats per floor, having a mean roof area of 434m². Flat dwellings from both *Brasília* and *Águas Claras*, did not have individual gardens, these were commonly found within communal grounds surrounding the residential building blocks.

The majority of the dwellings from *Taguatinga* and *Candangolândia* were ground floor bungalow houses (86%) the remaining were one story detached houses (14%). With a mean dwelling built area of 141 m², the houses had a mean roof area of 130m². These homes did not have a vegetated garden, instead, they had cemented yards of a mean 80m². Few of *Taguatinga and Candangolândia* dwellings did have a swimming pool (3.5%), with a mean volume of 35m³. No water features were found within the dwellings. Dwellings from *Ceilândia* and *Samambaia* were either ground floor bungalow houses (85%) or one storey terraced houses (15%) with a mean built area of 110m². Having a mean roof area of 97 m², most dwellings analysed had cemented yards with a mean 74m² area. No swimming pools or water features were found.

3.4 Water consumption

Annual water consumption data gathered from historic billing records ranged from a minimum 36m³ per dwelling per year to a maximum 732m³ per dwelling per year, and a mean ranging from 180 m³ to 481m³ per dwelling per year. It is observed that the higher the income, the higher the annual water consumption. High income house dwellings from *Lago Norte* and *Lago Sul* had the highest annual water consumption rate with a mean 481m³ per annum. Mid-high income flat dwellings from *Brasília* and *Águas Claras* presented a mean water consumption rate of 243m³/year, mid-low income house dwellings from *Taguatinga* and *Candangolândia* 216m³/year and low income house dwellings from *Ceilândia* and *Samambaia* 180m³/year (Figure 1). Overall, outdoor water consumption from external faucets represented 13% of domestic consumption and consisted mainly of garden irrigation and floor washing.

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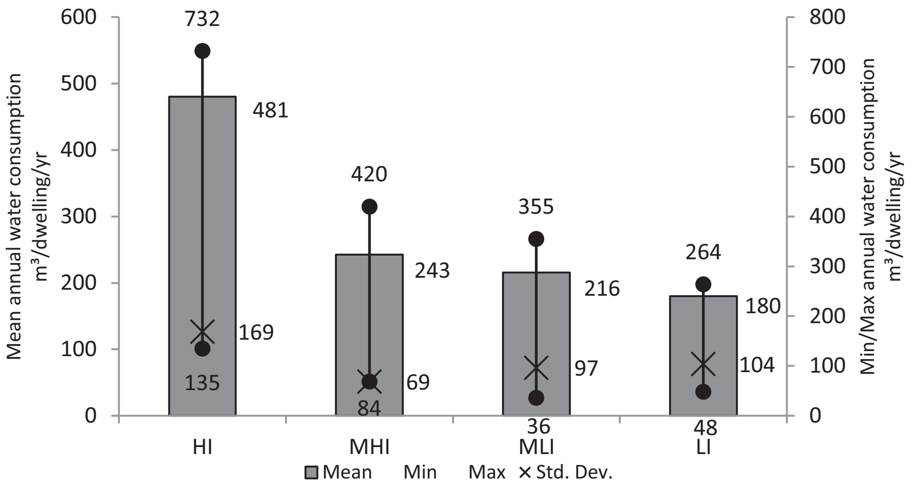

Figure 1. Annual water consumption per dwelling

3.5 Correlation and regression analysis

To evaluate the strength of statistical correlation between the variables of indoor water consumption, outdoor water consumption, number of residents, dwelling income, cost of water, built area and garden/yard area, a matrix of simple correlations was carried out using Pearson coefficient. Results shown in Table 2 indicates that indoor water consumption had a very strong relationship with water tariff (0.90) and dwelling built area (0.63), a substantial relationship with dwelling income (0.49) and a moderate relationship with the number of residents (0.37). Outdoor water consumption on the other hand, presented a substantial relationship with garden/yard area (0.49) and a moderate relationship with dwelling income (0.32). Dwelling income also had a substantial relationship with dwelling built area (0.47) and garden/yard area (0.42). These correlation coefficients are significant at the 1% or 5% level, that is, they are statistically significantly different from zero at 99% or 95% level of significance.

Multiple regressions allowed the development of indoor and outdoor water consumption models generating a prediction tool for domestic water consumption based on a set of explanatory variables. The estimated regression for indoor water consumption, displayed a relatively strong variation in function of number of residents, dwelling income, cost of water and built area, with R2 = 0.881 p< 0.001 (Equation 1). This value shows that 88.1% of the variance in indoor water consumption can be predicted from the number of residents, dwelling income, cost of water and built area.

$$D_{Indoor} = \underset{(2.40)}{3.82} + \underset{(3.19)}{0.11N_r} + \underset{(2.16)}{0.09I_d} + \underset{(5.79)}{0.71C_w} + \underset{(17.30)}{0.24A_b} \qquad (1)$$

$R^2 = 0.88$ $F = 192.5$

D_{Indoor} = Indoor Water Consumption (m³/month)
N_r = Number of Residents (person)
I_d = Dwelling Income (R$/month)
C_w = Cost of Water (R$/month)
A_b = Built Area (m²)
In parenthesis, the value of t-statistics

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Table 2. Correlation matrix

		Domestic Water Consumption (m^3/month)	No. of Residents	Dwelling Income (R$/month)	Cost of Water (R$/month)	Built Area (m^2)	Garden Area (m^2)	Outdoor Water Consumption (m^3/month)	Garden Water Cost (R$/month)
Domestic Water Consumption	Pearson Correlation	1	.365**	.489**	.905**	.632**	.190*	.095	.132
(m^3/month)	Sig. (2-tailed)		.000	.000	.000	.000	.048	.380	.220
	N	119	119	111	119	117	108	88	88
No. of Residents	Pearson Correlation	.365**	1	.032	.315**	.099	-.083	-.170	-.109
	Sig. (2-tailed)	.000		.742	.000	.289	.393	.114	.313
	N	119	119	111	119	117	108	88	88
Dwelling Income (R$/month)	Pearson Correlation	.489**	.032	1	.408**	.474**	.423**	.323**	.275*
	Sig. (2-tailed)	.000	.742		.000	.000	.000	.003	.011
	N	111	111	111	111	109	103	84	84
Cost of Water	Pearson Correlation	.905**	.315**	.408**	1	.475**	.184	.068	.081
(R$/month)	Sig. (2-tailed)	.000	.000	.000		.000	.057	.528	.452
	N	119	119	111	119	117	108	88	88
Built Area	Pearson Correlation	.632**	.099	.474**	.475**	1	.326**	-.074	-.006
(m^2)	Sig. (2-tailed)	.000	.289	.000	.000		.001	.495	.959
	N	117	117	109	117	117	108	88	88
Garden Area	Pearson Correlation	.190*	-.083	.423**	.184	.326**	1	.491**	.357**
(m^2)	Sig. (2-tailed)	.048	.393	.000	.057	.001		.000	.001
	N	108	108	103	108	108	108	87	87
Outdoor Water Consumption	Pearson Correlation	.095	-.170	.323**	.068	-.074	.491**	1	.937**
(m^3/month)	Sig. (2-tailed)	.380	.114	.003	.528	.495	.000		.000
	N	88	88	84	88	88	87	88	88
Garden Water Cost (R$/month)	Pearson Correlation	.132	-.109	.275*	.081	-.006	.357**	.937**	1
	Sig. (2-tailed)	.220	.313	.011	.452	.959	.001	.000	
	N	88	88	84	88	88	87	88	88

**Correlation is significant at the 0.01 level (2-tailed).
*Correlation is significant at the 0.05 level (2-tailed).

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Since F=192 is significant, the regression equation helps us to understand the relationship between the water consumption and the other variables. Predictions from this model are reliable and statistically significant at p=0.001 and F=192.446. This provides evidence of existence of a linear relationship between water consumption and the explanatory variables. The t-statistics for the above independent variables and their associated 2-tailed p-values indicated a reliability of p<0.033. The constant of the estimated indoor water consumption model equivalent to 3.82, suggests that dwellings consume a minimum of subsistence amount of 3.82 m^3 of water per month, regardless of the dwelling's income, number of residents, cost of water and built area.

Equation 2 presents the regression for monthly outdoor water consumption. The result shows a near perfect relationship with garden/yard area and cost of water, with $R^2 = 0.906$ (116), p<0.001, indicating that 90.6% of the variance in outdoor water consumption can be predicted from garden/yard area and cost of water. Predictions from this model are reliable and statistically significant with p=0.000 and F=405.933.

$$D_{Outdoor} = \underset{(2.58)}{1.21} + \underset{(24.24)}{0.87C_w} + \underset{(5.02)}{0.18A_{gf}} \qquad (2)$$

$R^2 = 0.90$ F = 405.9

$D_{Outdoor}$ = Outdoor Water Consumption (m^3/month)
C_w= Cost of Water (R$/month)
A_{gf} = Garden/Floor Area (m^2)
In parenthesis, the value of t-statistics

The result indicates that the cost of water has a greater effect on the predicted value of outdoor water consumption than garden/floor area. T-statistics and their associated 2-tailed p-values indicated a reliability of p<0.012. The outdoor water consumption model indicates a constant value of 1.21, which suggests that dwellings consume a minimum amount of 1.21 m^3 of water per month for garden irrigation and/or floor washing, regardless of the cost of water and garden/yard area. The model also shows that outdoor water consumption is predicted to rise 0.18 m^3/month for every m^2 of garden/floor area. Although the cost of water was expected to be negatively related to outdoor water consumption, our equation indicates that the relationship is positive. This might be due to the fact that water tariff is low, and the cost of water does not affect outdoor water consumption negatively, since water demand is inelastic to water consumption. Moreover, there is no substitute for water, a low level of consumer's perception on water rates structure and the water tariff represents small fraction of household income.

4. CONCLUSION

Based on the hypothesis that variables such as cost of water, family income, household size and building typology affect the way water is consumed this paper sets out to understand what lies behind domestic water consumption in the Federal District, Brazil. Overall, a direct relationship between dwelling income and water consumption could be observed, where, the higher the income, the higher the water consumption rate. High income dwellings presented an average of 481m^3 per year, mid-high income flat dwellings an average of 243m^3, mid-low income dwellings an average of 216m^3 and low income dwellings an average of 180m^3 per year.

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The correlation analysis carried out shows a good relationship between indoor water consumption and built area (0.63), dwelling income (0.49), and number of residents (0.37). Estimated water consumption function has shown a relationship between dwelling income and built area. The coefficient of cost of water presented a positive relationship showing that water demand is inelastic to water price due to the fact that water tariff is low, there is no substitute for water, and water tariff represents a small fraction of household income.

Result demonstrate that, like in other studies (Arbués, García-Valiñas et al. 2003; Barrett and Wallace 2009; Schleich and Hillenbrand 2009) household size is positively correlated with domestic water consumption. Water demand is predicted to rise 0.11 m^3/month for every additional resident per dwelling. The estimated equation shows that dwelling income has an influence over indoor water consumption, where, the higher the income, the greater the consumption at 0.09 m^3/month for every R$/month of income. Also, results indicate that the larger the dwelling, the higher the consumption at 0.24 m^3/month per built area. Result similar to a series of studies that show that domestic water consumption varies accordingly to residential buildings typology (Loh and Coghlam, 2003; Russac et al., 1991; Zhang and Brown, 2005).

Although the cost of water was expected to be negatively related to domestic water consumption, where, the higher the cost of water, the lower the consumption, the estimated model indicates a positive relationship. This positive relationship is found in numerous studies for other countries; they have shown that domestic water consumption is price-inelastic (Worthington and Hoffman, 2008).

Nauges and Whittinghton (2010) review what is known and what is missing from that literature thus far that uses data from household surveys to estimate household water demand functions in less developed countries. The findings from the literature on the main determinants of water demand in these countries suggest that, despite heterogeneity in places and time periods studied, authors agree on the inelasticity of water demand in less developed countries.

This positive relationship might also be due to a low water tariff structure, where the cost of water does not affect indoor water consumption negatively. Arbués *et al.* (2003) argues that water demand is inelastic to water price since there are no substitutes for water and because there is a low level of consumer perception on rate structures. On the other hand, expenditure in water represents a very small fraction of household income (Kostas and Chrisostomos, 2006 and Martinez, 2002).

Through multiple regression, indoor and outdoor water consumption functions were estimated for the Federal District. Estimated water demand functions have shown a strong relationship between water consumption and household income, built area and number of residents. One of the main conclusions drawn from this study is that variables of cost of water, family income, household size and building typology are directly related and affect both indoor and outdoor water consumption, and therefore, should be considered for adequate urban water demand predictions.

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