Price Reform and Household Demand for Electricity

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Abstract

This paper uses an estimated model of residential electricity demand to examine the impact of proposed tariff changes on a representative sample of 130 Barbadian households. The estimated equation results suggest that the price elasticities of demand for particular appliances varied significantly, with households that utilize solar water heating being more price elastic than households that utilize air conditioning and electric water heating electric heating. The income effects were, however, statistically insignificant, as they may have been captured by choices of appliances rather than utilisation. The estimated model results were then employed to examine the effect of a proposed change in the tariff structure for electricity in Barbados. The simulated results seem to indicate that changes in the electricity rate structure are likely to have very little impact on households demand for electricity. However, changes in consumption patterns could occur within upper consumption and upper income households.

JEL Classification: Q41; C24; O54

Keywords: Electricity demand; Heckman estimator; Developing country

1. Introduction

The Barbados Light and Power Company (BL&P), which under current law, is the only electricity service provider in Barbados, has recently been given permission by the Fair Trading Commission, to submit its application for a review to its rates and rate structure, which have not been changed since 1983. This action was required as it was thought that the current rates do not permit the BL&P to maintain its reliability and efficiency as well as to satisfy lenders and attract new capital. One aspect of these proposed reforms that are likely to be important to the deliberations between the Fair Trading Commission (FTC) and the BL&P is the effects of these price revisions on consumption which will depend on the price elasticity of demand for electricity. In the case where the price elasticity of demand is low this provides some justification for the FTC to grant permission to the BL&P to change its rates and rate structure; in contrast, when the price elasticity is high the FTC has little reason to allow the BL&P to make these price revisions. This decision obviously would require knowledge of demand for electricity studies in as much details as possible.

This paper estimates a demand for electricity function for Barbados to assess the impact of the proposed rate changes on consumers. For the first time, survey data on Barbadian households are utilised. Past electricity demand studies for Barbados (Cox, 1983; Durant, 1991; Mitchell, 2009) have not addressed policy issues like the one proposed above and have been based on aggregate time series macro data of the country along the lines of Wolde-Rufael (2005) for African countries and Liang, Fan and Wei (2007) for China. For instance, aggregate electricity consumption is usually regressed on an income variable and a price variable over various time periods with stationary and non-stationary time series econometrics techniques. Some authors have recently shown that the use of micro-level data, which reflects individual and household behaviour more closely, can add detail to an understanding of the nature of consumer responses (Tiwari, 2000; Holtedahl & Joutz, 2004; Louw, Conradie, Howells, & Dekenah, 2008). Microeconomic approaches to energy and electricity demand modelling also enable an analysis across different heterogeneous household groups and allow for the incorporation of a wide variety of household characteristics within the estimated equations (Hawdon, 1992).

In order to simulate the effects of the proposed tariff changes discussed above, the electricity demand function is used to examine the impact of the tariff changes on the Barbadian consumers, by adjusting the price variables while leaving the other variables unchanged. The results obtained can not only reveal likely demand-side effects but also distributional changes as well. The results from the study would therefore be of use to consumer groups, policymakers as well as officials from the Barbados Light and Power involved in forecasting demand for electricity on the island.

In the following section, the background to the rate adjustment is discussed. After that, the empirical approach, which consists of the conceptual set-up, the econometric methodology and data, is presented. Next the statistical results are discussed and the paper closes with a brief conclusion.

2. Background to Rate Application

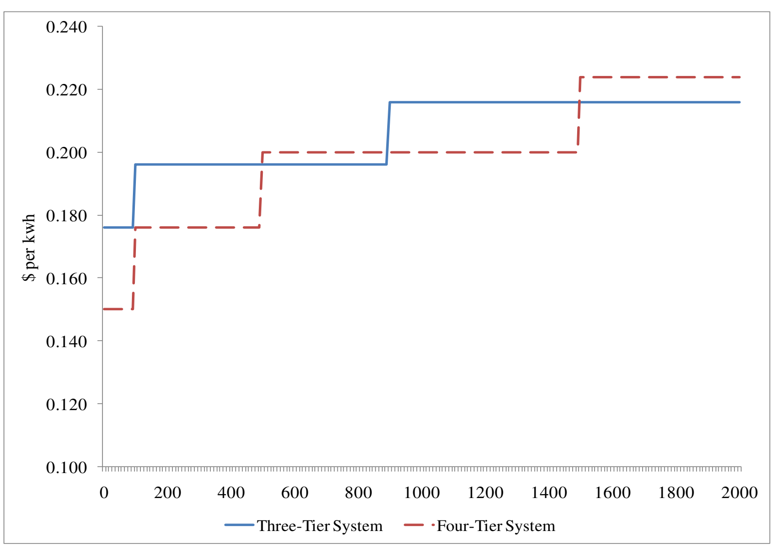
The BL&P submitted an application for a review of its rates and rate structure to the FTC on May 8, 2009. The previous application for a review of rates by the BL&P was in 1983 when the then Public Utilities Board granted the Company an increase in its basic electricity rates. The BL&P indicated that the present rate application is being made because the current rates are inadequate for the Company to continue to meet its operating and maintenance expenses, satisfy lenders and attract new capital to replace older plant. Some of the main objectives of the rate application as outlined by the BL&P include: (i) the provision of fair rates and to apportion the total cost of service among the different classes of customers in a fair manner, sensitive to any impact on customers; (ii) to encourage customers to use electricity more efficiently by, revising the existing rates to more closely reflect the unit cost of serving customers, thereby reducing the inter and intra class subsidies that presently exist; (iii) to shift the 2.64 cents per kWh of fuel cost from the base energy rate to the Fuel Clause Adjustment (FCA) so that the full fuel cost is collected through the Fuel Clause Adjustment; (iv) to revise the Service Charges so that they may more closely reflect the cost of service; and (v) to lessen the rate impact of the overall revenue increase on customers in the lower income bracket.

The proposed rate application is expected to affect the structure of all of the BL&P's existing tariff groups. The Domestic Service group services residential consumers and changes to its fixed domestic customer charge and the base energy charge are likely. Currently domestic service consumers are first charged a BDS$3 fixed customer fee, on top of an inclining three-tier price schedule (Figure 1). The cost for consumers using up to 100 kWh is presently BDS$0.176

per kWh. Those customers utilizing in excess of 100 kWh are charged BDS$0.196 for the next 900 kWh and BDS$0.216 for each additional kWh in excess of 1000 kWh. The BL&P is therefore seeking permission to adjust the consumer price to an inclining block fee where customers that consume less than 100 kWh on average over a twelve month period will be asked to pay a BDS$6 monthly customer charge, while the consumer price will increase to BDS$10 for those with consumption levels between 101 and 500 kWh and BDS$14 for those customers consuming a monthly twelve month average above 500 kWh.

A four-tier inclining block rate is proposed for the base energy charge that will see the exclusion of 2.64 cents/kWh that presently goes towards the fuel cost being shifted from the base energy rate to the Fuel Clause Adjustment (FCA). In addition, customers using up to 100 kWh will be charged BDS$0.150 per kWh, while those consumers utilising in excess of 100 kWh would have to pay BDS$0.176 per kWh for the next 400 kWh. The price for customers using in excess of 500 kWh will be BDS$0.200 per kWh for the next 1,000 kWh and BDS$0.224 per kWh for any consumption greater than 1,500 kWh (Figure 1).

Figure 1: Current and Proposed Marginal Price Schedule for Residential Electricity



3. Empirical Approach

3.1 Conceptual Framework

In electricity demand studies it is customary (Dubin & McFadden, 1984; Filippini & Pachauri, 2004; Holtedahl & Joutz, 2004; Louw, Conradie, Howells, & Dekenah, 2008) to assume that the household demand for electricity is derived from the demand of the commodity itself (electricity) and the service that electricity provides (i.e. being able to operate domestic appliances, televisions, etc.). Therefore, a general household utility function incorporating the household's electricity demand would generally take the form:

$$U = u(x\{E, A, F\}, y, z) \tag{1}$$

$$s.t. \quad m < p_x x + p_y y$$

where x is the energy services consumed by the household, E is electricity, A are appliances, F are other fuels consumed by the household, y are goods and services consumed by the household, z represents the tastes and preferences of the household, m is the income of the household, p_x is the price of energy services and p_y are the prices of the other goods and services consumed. With maximising household utility being the objective, the Lagrange function given below can be formed:

$$\mathcal{L} = u(x\{E, A, F\}, y, z) - \lambda(p_x x + p_y y - m) \quad (2)$$

The first-order conditions from this Lagrange function allow us to derive the Marshallian demand function for the household's demand for energy services as follows:

$$x = x^*(p_x, m, z, \varepsilon) \quad (3)$$

The household's tastes and preferences (z) are incorporated in the demand function as they form part of the decision process in determining which fuels are used by the household as well as they reflect any externalities that may impact on health and productivity. The stochastic term, ε, is added to the equation for estimation purposes.

3.2 Econometric Approach

Like most electricity providers around the world, the price schedule of electricity services supplied in Barbados is non-linear. Given this non-linear pricing schedule, Reiss and White (2005) note that the stochastic term in Equation (3) conveys information about the willingness-to-pay of the consumer, i.e. customers self-select the marginal price they are willing to pay. The demand function for the household under a three-tier pricing schedule therefore takes the following form:

$$x^* = \begin{cases} x(p_x^1, m^1, z; \beta) + \varepsilon & if \;\; \varepsilon < c_1 \\ x(p_x^2, m^2, z; \beta) + \varepsilon & if \; c_1 < \; \varepsilon < c_2 \\ x(p_x^3, m^3, z; \beta) + \varepsilon & if \; c_2 < \varepsilon < c_3 \end{cases} \tag{4}$$

Equation (4) is a censored regression model that can be estimated using the usual censored regression modelling techniques. The model is estimated utilising the Heckman two-step approach (Cameron & Trivedi, 2005).

The demand for electricity services is a derived demand where individuals desire to consume certain energy-using appliances and therefore require electricity to power these durable goods(Dubin & McFadden, 1984). In this instance, modelling the electricity demand for individual appliances would be preferred; however, data at this level of disaggregation is not available. Consequently, electricity demand is modelled as the sum of the electricity used by i appliance categories:

$$x_i = x_i^*(p_x, m, z; \beta) + \varepsilon_i \tag{5}$$

where $\beta = \sum_i d_i \beta_i$ are the slope coefficients that depend on the household's holdings of particular appliances with d_i being a dummy variable that takes a value of 1 if the household holds appliance i and 0 otherwise. Following (Dubin & McFadden, 1984), the choice of space cooling and water heating are isolated, while the other appliances are treated as statistically exogenous. There are two motivations for making this simplifying assumption: (1) this approach increases the degrees of freedom as a smaller set of interaction terms are employed, and; (2) space and water heating are primary consumption decisions that require major retrofitting of the house. In contrast, the other appliances usually do not require such critical investments.

3.3 Data

The empirical electricity demand data employed in this study is taken from the Residential Customer Survey (RCS) of consumers conducted by the BL&P in 1997 as part of a larger study. The survey collects information on the electricity consumed by households, their portfolio of appliance holdings along with demographic data. It provides information on 129 Barbadian households, which is less than 0.2 percent of households on the island. It is a nationally representative probability sample of households, with representative sub samples among usage levels. The survey was conducted by in-home interviews. Interviewers inventory the household's appliances, assess physical characteristics of the residence, and collect demographic information. To minimize measurement error, each household's metered energy consumption data are sourced directly from the electric utility. Approximately one hundred and thirty-three interviews were completed among residential customers, thus representing a response rate of 97 per cent.

The consumption of electricity, x, is approximated by the monthly electricity usage. Two price variables are employed in the study: the average price of electricity and the marginal price of electricity. The average price is obtained by dividing the consumer's monthly bill in Barbados dollars by the amount of electricity (kWh) used, while the marginal price is the highest per kWh tier price that the consumer presently pays.

Income is approximated by an interval variable ranging from 1, where the household's monthly income is less than BDS$1,200 to 5, if the household's income exceeds BDS $10,000 on a monthly basis. In terms of other household characteristics, variables representing the number of persons and bedrooms in the household are employed as well as the type of housing unit. The appliance portfolio is made up of dummy variables for the existence of televisions, refrigerator, washing machine, dryer, freezer, electric stove, toaster oven, wall fan, and security lighting. On the whole, most customers (over 70 percent), tend to consume 100 – 900 kWh on a monthly basis and therefore fall in tier 2 of the Barbados Light and Power three-tier price schedule. Of the remainder, just fewer than 20 percent consume more than 900 kWh on a monthly basis while a relatively small proportion of Barbadian households (less than 10 percent) consume less than 100 kWh of electricity on a monthly basis.

Descriptive statistics for the variables utilised in the study are shown in Table 2. They suggest that the average Barbadian household uses about 546 kWh per month which translates to about BDS$105, or about BDS$0.19 per kWh. The average household sampled had a monthly income of BDS$4,400, lived in three-bedroom house with three individuals in the household.

Table 1: Descriptive Statistics

		Mean	Max	Min	Std. Dev.	Skewness	Kurtosis	Jarque-Bera
MONKWH	Monthly	546.426	2636.000	54.000	449.038	1.749	6.889	147.076*

	electricity usage of households							
P	Average price of electricity (monthly electricity bill/monthly electricity usage)	0.190	0.210	0.180	0.006	0.703	5.136	35.139*
MP	Marginal price of electricity	0.203	0.220	0.180	0.009	0.484	3.980	10.199*
INCOME	Monthly Income of household	3.124	6.000	0.000	1.541	0.241	2.370	3.386
NTEL	Number of televisions	1.085	5.000	0.000	1.250	0.681	2.483	11.417*
PERSONS	Number of persons in household	3.271	6.000	0.000	1.638	0.319	2.224	5.423
BEDROOMS	Number of bedrooms in residence	3.085	6.000	0.000	1.125	-0.036	4.195	7.707*
FRIGE	Household has a refrigerator	0.977	1.000	0.000	0.151	-6.326	41.024	8631.741*
WASHING	Household has a washing	0.853	1.000	0.000	0.356	-1.991	4.962	105.882*

	machine							
DRYER	Household has a dryer	0.147	1.000	0.000	0.356	1.991	4.962	105.882*
FREEZER	Household has a freezer	0.488	1.000	0.000	0.502	0.047	1.002	21.500*
ELESTOVE	Household has an electric stove	0.318	1.000	0.000	0.467	0.782	1.612	23.515*
TOASTERO	Household has a toaster oven	0.411	1.000	0.000	0.494	0.362	1.131	21.593*
WALLFAN	Household has a wall fan	0.690	1.000	0.000	0.464	-0.821	1.674	23.945*
MULUNT	Household is a multi-unit property	0.093	1.000	0.000	0.292	2.802	8.853	352.937*
SELIGHT	Household has security lighting	0.178	1.000	0.000	0.384	1.681	3.826	64.416*
ELECHEAT	Household uses electric water heating	0.186	1.000	0.000	0.391	1.614	3.604	57.935*
AC	Household has air conditioning	0.248	1.000	0.000	0.434	1.167	2.361	31.458*
SOLAR	Household has solar water heating	0.318	1.000	0.000	0.467	0.782	1.612	23.515*

4. Results

4.1 Electricity Demand Function

Table 2 displays the estimated electricity demand function for Barbados using the Heckman two-step procedure, where the Mills ratios are omitted because their economic interpretation is unclear. The second stage of the Heckman estimator was estimated using ordinary least squares (OLS) as well as full information maximum likelihood techniques. However, the results from both techniques were quite similar. Consequently, only the findings from the OLS estimation approach are displayed, with the reported standard errors being White heteroskedasticity-consistent. The model is able to account for a large proportion of the cross-sectional variation in electricity consumption, 85 percent. The calculated Jarque-Bera statistic for the model residuals suggested that the null hypothesis of normality could not be rejected at normal levels of testing. Given that the model is a reasonably adequate representation of electricity demand in Barbados, an analysis of the estimated coefficient estimates is now given. The coefficient estimates on the appliance holdings show the proportional change in electricity consumption based on consumers' portfolio holdings (washing and elestove). The other appliances were statistically insignificant and therefore dropped out with the use of stepwise least squares. The coefficient for the existence of a washing machine was positive and statistically significant, suggesting that the presence of a washing machine is noteworthy in explaining the demand for electricity in Barbadian households.

It was somewhat surprising that the number of bedrooms had a significant positive effect on the demand for electricity while the size of the household effect was insignificant. One would have expected that household size would have positive coefficients as larger families would consume more electricity, as well as utilise more electricity to light and cool or heat the rooms in the house depending on the seasonal requirement. Halvorsen (1975), however, notes that households with larger numbers may substitute electrical power consumption with the use of natural gas for certain requirements that would be energy intensive.

Table 2: Electricity Demand Model Coefficient Estimates – Heckman Two-Step Approach

Explanatory Variable	*Baseline Use*	*Interaction Effects*		
		Electric Water Heating	Solar Water Heating	Air Conditioning
Constant	1.914 (5.113)	-175.589 (33.224)***	9.007 (4.157)**	-9.564 (4.015)**
p	-0.183 (0.0366)***	-1.272 (0.237)***	-	-
mp	0.061 (0.019)***	-0.473 (0.092)***	0.055 (0.025)**	-0.057 (0.024)**
income	0.029 (0.042)	-	-0.105 (0.064)*	0.135 (0.057)**
bedrooms	0.099 (0.034)***	-0.145** (0.061)	-	-
washing	0.259 (0.112)**	-	-	-
elestove	0.085 (0.076)	-	-	-

mulunt	-0.243 (0.226)	-	-	-
persons	-	-	0.086 (0.046)*	-
R-squared	0.853			
s.e.	0.335			
Jarque-Bera	0.207 [0.901]			

Notes: (1) White heteroskedasticity-consistent standard errors provided in parentheses, while p-values are given in parentheses.

(2) ***, ** and * indicates significance at the 1, 5 and 10 percent levels of significance.

Due to the existence of non-linear pricing, the coefficients on the marginal and average price as well as income variables cannot be interpreted as elasticities. As a result, following Reiss and White (2005) the non-linear price elasticity which accounts for the substitution and income effects is estimated using the following equation:

$$\eta = \frac{mp}{x} . [\beta_{mp} + \beta_y x] \tag{6}$$

The calculated price and income elasticities are provided for all households as well as those with electric water heating, air conditioning and solar water heating. The computed price elasticity of demand for Barbadian households was -0.778, which was somewhat lower than that obtained by Houthakker (1951), but in line with studies which also use less aggregated data (Parti & Parti, 1980; Dubin & McFadden, 1984; Munley, Taylor, & Formby, 1990; Maddock, Castano, & Vella, 1992). For electric water heating, the price elasticity of demand fell to -0.756, suggesting that these households tend to be less price sensitive relative to the average Barbadian household. In contrast, households with solar water heaters were more prices sensitive, which might be explain by the fact that these households substitute the electricity demanding water heaters, for the heater that had no reliance on electricity. The price elasticity of households with air conditioning was generally consistent with those obtain for the average household.

Table 3: Price and Income Elasticities for Barbadian Households

Explanatory Variable	*Price Elasticity*	*Income Elasticity*
All households	-0.778	0.015
Electric water heating households	-0.756	-
Air conditioning households	-0.775	0.031
Solar water heating households	-0.783	-0.002

The income elasticity of demands was calculated in a similar fashion as the price elasticities. The income elasticities estimates were small, suggesting that the demand for electricity is relatively income inelastic. As noted earlier, electricity demand is a derived demand that is based on the household's portfolio of appliances. Therefore fluctuations in demand for electricity seem to be more a function of appliance holdings rather than income fluctuations. These results are similar to those obtained by Reiss and White (2002). Note that the income elasticity for households with solar water heating was negative reflecting the substitution effect arising from the use of solar power to provide water heating.

4.2 Projected Impact of Rates Adjustment on Households

The paper now turns to investigating the impact of the proposed new rate structure on households demand for electricity. Table 4 demonstrates that the proposed changes in the electricity rates would result in a reduction in the mean marginal price of electricity. Graphically, Figure 1 shows that the proposed new price schedule lies below and above existing price schedule depending on the consumption level. The proposed four-tier system of prices will see the marginal price of electricity for households within the sample move from $0.198 per kWh to $0.184 per kWh, a decrease of 7%. Consumers that have consumption patterns less than 500 kWh per month and between 1000 and 1500 kWh per month would benefit most from the changes in the marginal prices. Households however, with consumption levels in excess of 1500 kWh between 500 and 1000 kWh per month will face a higher marginal price.

Table 4: Marginal and Average Prices Before and After Rate Adjustments

Household Monthly Consumption	*Existing Average Price*	*Proposed Average Price*	*Percentage Change*	*Existing Marginal Price*	*Proposed Marginal Price*	*Percentage Change*
Under 500 kWh	0.462	0.495	7.1	0.195	0.174	-10.5
500 to 1000 kWh	0.458	0.486	6.1	0.196	0.2	2
1000 to 1500 kWh	0.46	0.486	5.6	0.216	0.2	-7.4
More than 1500 kWh	0.467	0.492	5.5	0.216	0.224	3.7
Sample	0.461	0.492	6.7	0.198	0.184	-7

Table 4 above further suggest that the proposed changes in the rate structure will result in an increase in the average price of electricity for households at all consumption levels. This result will occur due to the proposed increase in the monthly customer charge and the shifting of the fuel related $0.0264 from the base charge to the fuel clause adjustment.

The results of the simulation exercises to examine the impact of the proposed rates on household electricity consumption are shown in Table 5. Households will generally alter their electricity consumption very little in response to the proposed changes to the four-tier structure and the increase in price. The results indicate that the average monthly electricity consumption within the sample employed here will be 5 kWh lower due to marginal price changes offsetting much of the impact of the average price increases. The model predicts that notable reductions in demand will only occur within upper income households. This is confirmed by the 5.6% decrease in demand predicted for households consuming over 1500 kWh per month as households with these consumption levels are normally within the upper income bracket. Households with monthly consumption patterns between 500 kWh and 1000 kWh per month are expected to make the greater percentage adjustment in their demand for electricity. These households are likely to contract their monthly consumption by 6.2%.

Table 5: Distributional kWh Monthly Impact of Rate Adjustments

	Average Price Effect	*Marginal Price Effect*	*Total Effect*
Monthly Household Income			
Under $1200	-15 (-5.7%)	21 (7.3%)	6 (1.6%)
$1200 - $2399	-19 (-6.3%)	19 (8.1%)	0 (0.0%)

$2400 - $4399	-22 (-5.5%)	21 (5.9%)	-1 (-0.4%)
$4400 - $6399	-26 (-4.6%)	22 (4.8%)	-4 (-0.2%)
$6400 - $10000	-36 (-4.1%)	22 (3.5%)	-14 (-0.6%)
More than $10000	-40 (-4.0%)	10 (1.1%)	-30 (-3.0%)
Monthly Consumption Band			
Under 500 kWh	-15 (-5.8%)	24 (8.4%)	9 (2.6%)
500 to 1000 kWh	-33 (-4.6%)	-11 (-1.5%)	-44 (-6.2%)
1000 to 1500 kWh	-44 (-3.7%)	58 (4.9%)	14 (1.2%)
More than 1500 kWh	-70 (-3.3%)	-47 (-2.3%)	-117 (-5.6%)
Sample	-24 (-5.2%)	19 (5.5%)	-5 (0.0%)

Note: percentage changes given parentheses below values

The BL&P indicated that the proposed rate structure is designed to achieve a number of objectives. Evaluating how the proposed new pricing structure will achieve those objectives is not very simple; however some inferences can be made from the results. The structure of the new pricing system seem likely to achieve its primary objective of raising additional revenue as demonstrated by the across the board increase in the average price. The achievement of the secondary objective of minimizing the price impact on the lower income households is also evident. Low income households within the sample consume less than 500 kWh per month and therefore will benefit from a significant reduction in their marginal price. The objective of encouraging households to use electricity more efficiently and thus promote energy conservation will also likely be accomplished. The increase in marginal prices for higher levels of consumption will have the effect of lowering significantly the demand for electricity among households within the high and middle consumption bands.

5. Conclusions

With a review of the rates and rate structure of the Barbados Light and Power Company forthcoming, this paper estimated, for the first time, an electricity demand function using survey data of a sample of 130 Barbadian customers. This function is then used to project the impact of the proposed change in the rates and rate structure on Barbadian households. As the demand for electricity services is a derived demand and data for the electricity demand for individual appliances is not available, electricity demand is modelled as the sum of the electricity used by i appliance categories. Following Dubin and McFadden (1984), the choice of space cooling and water heating are isolated in this paper, while the other appliances are treated as statistically exogenous. The non-linear pricing structure in Barbados is set up as a censored regression and estimated utilising the Heckman two-step approach where, due to the existence of non-linear pricing, Reiss and White (2002) coefficients on the marginal and average price as well as income variables are computed.

The reported results suggest that the price elasticities of demand for particular appliances varied significantly, with households with solar water heating more price elastic than air conditioning and electric water heating. The income effects were, however, statistically insignificant as these effects may have been captured by choices of appliances rather than utilisation and agree with studies by Parti and Parti (1980) and Dubin and McFadden (1984). The income elasticity for households with solar water heating was found to be negative, probably reflecting the substitution effect arising from the use of solar power to provide water heating. The database also allowed the authors to breakdown price and income elasticities by individual households and these results suggest that middle-income households tend to be more prices sensitive, even relative to low income households, indicating that the middle-income household may be more able to reduce their usage of discretionary appliances.

The impact of the introduction of the new tariff structure was also analysed and revealed that households with consumption patterns under 500 kWh will fear much better than higher consumption households from changes in the proposed rate structure. In general households will vary their consumption very little as a result of the introduction of the new rate structure. The more significant reduction in demand for electricity is expected among upper income and upper consumption households. In essence, the findings imply that the proposed new rate structure is, generally, not likely to have a significant influence on households demand for electricity, giving credence to the Fair Trade Commission's recent decision to approve the BLP rate changes with some amendments.

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