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Elasticities of Electricity Demand in Urban Indian Households

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Abstract

Energy demand, and in particular electricity demand in India has been growing at a very rapid rate over the last decade. Given, current trends in population growth, industrialisation, urbanisation, modernisation and income growth, electricity consumption is expected to increase substantially in the coming decades as well. Tariff reforms could play a potentially important role as a demand side management tool in India. However, the effects of any price revisions on consumption will depend on the price elasticity of demand for electricity. In the past, electricity demand studies for India published in international journals have been based on aggregate macro data at the country or sub-national/ state level. In this paper, price and income elasticities of electricity demand in the residential sector of all urban areas of India are estimated for the first time using disaggregate level survey data for over thirty thousand households. Three electricity demand functions have been estimated using monthly data for the following seasons: winter, monsoon and summer. The results show electricity demand is income and price inelastic in all three seasons, and that household, demographic and geographical variables are important in determining electricity demand, something that is not possible to determine using aggregate macro models alone.

Key Words Residential electricity demand, price elasticity, income elasticity

Short Title Electricity demand in Indian households

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1. Introduction

Energy demand, and in particular electricity demand in India has been growing at a very rapid rate over the last decade. Given, current trends in population growth, industrialisation, urbanisation, modernisation and income growth, electricity consumption is expected to increase substantially in the coming decades as well. This implies enormous new financial investments will be needed to meet demand in this sector.

Currently, the electricity sector is characterised by chronic power shortages and poor power quality. With demand exceeding supply, severe peak and energy shortages continue to plague the sector. While the government opened up the power generation sector to private investments in 1991, the State Electricity Boards (SEBs) continue to be the main agencies responsible for the generation and supply of electricity in India today. The elementary problem being faced by the power sector is the poor financial conditions of these State Electricity Boards. This has resulted in inadequate investment in additional generation capacity, which is likely to further exacerbate the existing gap between power supply and demand.

Clearly, there is a large role and potential for demand side management (DSM) programmes in India. The Government of India, through new Energy Conservation legislation is seeking to implement a host of such programmes within the country. One of the key elements of the DSM programmes is the introduction of rational cost-of-service based tariffs for power within the country. The price of power is currently set by the State in India and a high degree of cross-subsidization between sectors continues to exist, with average electricity tariffs being generally below the costs of power generation and distribution. This has tended to encourage inefficient use of electricity in the subsidized domestic sectors. A revision of electricity tariff rates is thus urgently needed.

The case for tariff reform in India is thus clear. However, the effects of any price revisions on consumption will depend on the price elasticity of demand for electricity. In the past, electricity demand studies for India published in international journals have been based on aggregate macro data at the country or sub-national/ state level[1]. 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[2]. 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 (see Hawdon (1992)).

In this paper, price and income elasticities of electricity demand in the residential sector of all urban areas of India are estimated for the first time using disaggregate household level survey data. Following Filippini (1999), we econometrically estimate electricity demand functions for urban Indian households using household data on total household expenditure (as a proxy for income), monetary expenditure on electricity and physical quantity of electricity consumed, number of household members, and a number of other geographic and socio-economic variables. The focus is on urban households because many rural households still do not have access to electricity in India and even for those who do, low incomes and lack of market accessibility, mean very low or even negligible electricity consumption.

Due to the fact that household electricity consumption in India shows seasonal variation over the year because of differences in the weather, three electricity demand functions have been estimated using monthly data for the following seasons: winter, monsoon and summer.

[1] See for instance Bose & Shukla (1999), Sengupta (1993), Roy, (1992), Uri (1979).
[2] See for instance D. Hawdon (1992), Nesbakken (1999).

In the following section, the theoretical framework and the empirical specification of the electricity demand model will be specified. The data used in the analysis and the statistical results will then be presented. Some concluding remarks follow in the last section of the paper.

2. An electricity demand model

The residential demand for electricity is a demand derived from the demand for a well-lit house, cooked food, hot water, etc., and can be specified using the basic framework of household production theory[3]. According to this theory, households purchase "goods" on the market which serve as inputs that are used in production processes, to produce the "commodities" which appear as arguments in the household's utility function. In our specific case, a household combines electricity and capital equipment to produce a composite energy commodity. Therefore, the household's utility function can be written as:

(1) $$U = U(S(E, CS), X; D, G)$$

where S is the composite energy commodity[4], E is electricity, CS is the capital stock consisting of appliances, X a purchased composite numeraire good that directly yields utility, while D and G represent demographic and geographic characteristics which determine the household's preferences.

In this framework the household's decision can be thought of as a two-stage optimisation problem (see Deaton and Muellbauer 1980). In the first stage, the consumer behaves as a firm, and the objective is to minimize the cost of producing S, whereas in the second stage of the optimisation problem, the household maximizes its utility.

Following household production theory the optimal input demand functions for E and CS can be written as:

(2) $$E = E\ (P_E, P_{CS}, Y; D, G)$$

(3) $$CS = CS(P_E, P_{CS}, Y; D, G)$$

where P_E is the electricity price, P_{CS} is the price of the electrical appliances and Y is income. Equations (2) and (3) reflect the long run equilibrium of the household. This model is static in that it assumes an instantaneous adjustment to new equilibrium values when prices or income change. Specifically, it is assumed that households can change both their rate of utilization and their stock of appliances. Therefore, we can expect two types of consumer responses to an increase in the price of electricity. In the short run, a household can lower the rate with which it utilizes its current stock of appliances, for example by adjusting the temperature of thermostats and water heaters. In the long run, since changes in P_E can result in changes in the relative prices of inputs, it may alter the mix of inputs. This would presumably lead to an adjustment of the household's capital stock; more electricity efficient appliances would substitute less electricity efficient appliances.

[3] For a clear presentation of the household production theory, see Becker (1975), Muth (1966) and Deaton and Muellbauer (1980). See Dubin (1985) and Flaig (1990) for an application of household production theory to electricity demand analysis.

[4] The production function of the composite energy commodity *S* can be written as: $S = S(E, CS)$

In this study, we use a single equation approach to modelling the residential demand for electricity in three different seasons: winter, summer and monsoon. We postulate that the demand for electricity depends on the price of electricity, the prices of substitute fuels, income and some demographic and geographic variables. Because of lack of data on electrical appliances we were not able to estimate equation (3).

The empirical model, based on equation (2), can be represented by the following demand function:

$$(4) \qquad E = E(P_E, P_K, P_G, Y, HS, AD, DST, DR1, DR2, DR3, DR4)$$

where

E	=	monthly residential electricity consumption per household in kWh;
P_E	=	electricity price in Rupees per kWh;
P_K	=	kerosene price in Rupees per litre;
P_G	=	L.P.G price in Rupees per kg;
Y	=	household personal income, approximated by total expenditure;
HS	=	number of household members living in the household;
AD	=	covered area of the dwelling in square feet;
DST	=	dummy variable to control for the difference of the size of town on electricity consumption. The value of the dummy variable is equal to 1 in case the household resides in a town with more than 1 million people; otherwise is 0.
DRi	=	dummy variable to control for the effect of regional differences on electricity consumption. The value of this dummy variable is equal to 1 for households living in region i (i = 1,2,3,4,); otherwise is 0.

The electricity demand of Indian households is therefore assumed to be a function of the electricity price, the price of substitutes (kerosene and LPG), household income, and some demographic and geographic characteristics (the household size, the dwelling size, the size of town where the household resides and the region where the household is living).

Cross-sectional data on appliance prices are not available. However, appliance prices faced by households can, apart from minor regional variations, be regarded as constant. Therefore, they may be excluded from the model without causing bias in estimation (see Halvorsen (1975)).

The variables number of household members living in the household and dwelling size, are included in the model in order to take into account the effect on electricity consumption of the size of the household.

The dummy variable for the size of the town is entered in the model, in order to take into account the impact of easier accessibility to a developed electric system and markets for electrical appliances on electricity consumption. The basic hypothesis is that households living in larger cities have greater possibilities to increase their electricity consumption.

The regional dummy variables are entered in the model, in order to take into account the impact of regional characteristics such as weather, degree of development and urbanization, on household electricity consumption. For this purpose we define, according to the information contained in our data set, five Indian regions. Thus, four regional dummy or discrete variables are introduced in the model (North-east, South, West and Central) to capture regional differences in the location of the household for the five different regions. Individuals residing in the states of the Northern region are taken as the reference households to avoid singularity due to the use of binary dummy variables in the model.

Estimation of demand function (3) requires the specification of a functional form. The log-log form offers an appropriate functional form for answering questions about price and income elasticities. The major advantage, of course, is that the estimated coefficients amount to elasticities, which are, therefore, assumed to be constant.

The equation to be estimated is:

$$\begin{aligned}(5)\quad \ln E = {} & \alpha_0 + \alpha_{PE} \ln P_E + \alpha_{PK} \ln P_K + \alpha_{PG} \ln P_G + \alpha_Y \ln Y + \alpha_{HS} \ln HS + \alpha_{AD} \ln AD \\ & + \alpha_{DTS} DTS + \alpha_{DR1} DR1 + \alpha_{DR2} DR2 + \alpha_{DR3} DR3 + \alpha_{DR4} DR4\end{aligned}$$

Since it is reasonable to assume that in a cross-section the observed difference in consumption of electricity represents not only variation in the utilization rate but also stock adjustment, estimates based on cross-sectional data are conventionally interpreted as long-run elasticities[5].

3. Data and estimation results

The household micro data used in this study is provided by the household expenditures survey Round 50 for the year 1993-94 from the National Sample Survey (NSS) conducted by the department of statistics of the Indian government (NSS, 1998). The survey for this year contains data from 30972 households living in Indian cities. This large data set contains information on quantity and value of household consumption with a reference period of the last 30 days preceding the date of the interview. In addition, data on a host of other socio-economic variables is collected through the survey. Prices are determined from the sample data as unit values, or in other words, monetary expenditures divided by physical quantities of consumption. The information for a single household is gathered only for one month. Thus, the households in the three seasonal datasets are not the same. The data set includes 7831 households for which information are available for winter months, 12510 for which information are available for summer months and 10631 for which information are available for monsoon months.

Tables 1 and 2 gives some statistical details on the variables employed in the estimation of the household demand model for electricity.

The values reported in table 1 and 2 on the variables employed in the econometric part of this paper; show that the three data sets (winter, summer, monsoon) are quite homogeneous. This result is not surprising, because the survey is performed every month over a period of a year by the Indian government using the same sample selection principle.

Table 1 also reveals a great deal of price variation is evident in the data. This can be attributed to differences in the pricing policies of the different State governments. In general, we can observe a positive correlation between household electricity demand and total expenditure per household as well as dwelling size.

[5] For a discussion about the interpretation of elasticity estimates with cross-section data see Thomas (1987).

Table 1: Description of variables

	Data set for winter months			Data set for summer months			Data set for monsoon months		
Variables	1. Quartile	Median	3. Quartile	1. Quartile	Median	3. Quartile	1. Quartile	Median	3. Quartile
Household electricity consumption (E) kWh	21	40	78	24	45	80	20	40	78
Electricity price (P_E) Rupees/kWh	0.74	0.94	1.19	0.75	1.00	1.19	0.71	0.93	1.16
Kerosene price (P_K) Rupees/litre	2.75	3	3.06	2.75	3	3.05	2.74	2.98	3.05
LPG price (P_G) Rupees/kg	6.40	6.71	7.06	6.60	6.98	7.18	6.30	6.69	7.02
Household size (HS)	3	4	6	3	4	6	3	4	6
Dwelling size (AD) Square feet	200	350	600	200	370	620	160	320	600
Total expenditure per household (Y) Rupees/month	1372	2032	3042	1354	2007	3051	1310	1962	2951

Table 2 Description of the dummy variables

Variable	Condition for which the variable value is equal to one	Frequency (%) Winter	Frequency (%) Summer	Frequency (%) Monsoon
DTS	Households living in a city with more than 1 million inhabitants	42.1	38.4	39.2
DR1	Households living in region Central	19.4	17.9	13.9
DR2	Households living in region North-East	18.6	19.9	20.3
DR3	Households living in region West	31.1	33.0	33.7
DR4	Households living in region South	11.6	10.9	12.3
DR5	Households living in region North	19.3	18.3	19.9

Table 2 shows that a high percentage of Indian households living in urban areas according to our sample live in very large cities (with a population of more than 1 million). Moreover, there is a higher concentration of sample households in the Western region of the country, as expected, as this comprises the main industrial belt of the country.

Table 3: Residential electricity demand estimates (t-ratios in parentheses)

Variable	Model Winter months	Model Summer months	Model Monsoon months
Constant	-2.427*** (-15.717)	-3.255*** (-17.141)	-0.972*** (-5.513)
ln P_E	-0.321*** (-20.888)	-0.160*** (-8.111)	-0.389*** (-22.803)
ln P_K	-0.190*** (-8.247)	-0.293*** (-10.217)	-0.145*** (-5.471)
ln P_G	-0.004 (-0.596)	0.626*** (6.960)	-0.549*** (-7.433)
ln Y	0.689*** (67.349)	0.658*** (52.282)	0.647*** (58.747)
ln HS	-0.002 (-1.918)	-0.002 (-1.883)	0.003*** (-2.897)
ln AD	0.219*** (32.282)	0.221*** (24.395)	0.180*** (25.704)
DTS	0.197*** (18.082)	0.208*** (15.212)	0.010*** (7.837)
DR1	0.007*** (3.802)	0.115*** (4.741)	0.002 (0.879)
DR2	-0.004 (-0.250)	-0.002*** (-3.992)	-0.010*** (-4.999)
DR3	0.177*** (11.415)	0.135*** (6.942)	0.158*** (8.637)
DR4	0.273*** (13.366)	0.336*** (13.130)	0.261*** (10.649)
R^2	0.502	0.504	0.453

*** significantly different from zero at the 99% confidence level.

The estimated coefficients and their associated t-values of the three seasonal household electricity demand models are presented in Table 3. The estimated functions are well behaved. Most of the parameter estimates are statistically significant. The goodness-of-fit (R^2) measure varies between 0.45 and 0.50. The explanatory power of the regressions is reasonably good given the individual cross-sectional data. Since electricity consumption and the regressors are in logarithms, the coefficients are interpretable as demand elasticities.

The price elasticity for electricity is significant in all three models and carries the expected sign. The estimated own price elasticity is -0.32 during the winter months, -0.39 during the monsoon months and –0.16 during the summer months. This suggests that a 1 percent increase in the price index of electricity will (ceteris paribus) result in approximately a 0.3-0.4 percent decline in household consumption of electricity during the winter and monsoon months and approximately a 0.2 percent decline during the summer months. This result indicates a price-inelastic demand for electricity and values lower than those reported in a previous study by Bose and Shukla (1999). Therefore, from an energy point of view we can say that there is little room for discouraging residential electricity consumption, using price increases alone. Finally, these results show that the electricity demand during the summer months is more price-inelastic than the electricity demand during the other seasons of the year. This difference can be explained by the fact that during the summer months, because of the high temperatures, the use of air conditioners and air ventilators is very intense and necessary.

The demand for electricity is responsive in all models to the level of income (Y) with an income elasticity of approximately 0.7. Since this elasticity is below unity, income growth apparently results in a less than proportional increase in electricity demand.

Household size, measured by the number of members of a household, seems not to influence in an important way the electricity consumption of Indian households. The estimated household size elasticity is significantly different from 0 at the 99% confidence level. However, the value of this elasticity is very low.

Dwelling size seems to significantly influence the electricity consumption of urban Indian households. The estimated Dwelling size elasticity is significantly different from 0 at the 99% confidence level in all the models and the value of this elasticity is approximately 0.2. Thus, for instance, a 1 percent increase in the number of squared feet (ceteris paribus) results in about a 0.2 percent increase in household consumption of electricity.

Finally, the urban and regional characteristics seem to significantly influence the electricity consumption of the Indian households. For instance, the result on the dummy variable related to the size of the town (DTS) indicate that households living in larger cities show a higher electricity consumption than those living in city with less than 1 million inhabitants. This result confirms the hypothesis that generally larger cities are characterized by more developed electricity distribution systems, and, therefore, more continuous access to electricity.

The coefficients of the regional dummy variables indicate that, ceteris paribus, household living in Central and Southern regions show lower electricity consumption than those living in regions of the North-east, West and North. These differences can be explained by important differences in the overall level of development of these regions and differing weather conditions between these regions.

In general, the values of the own price elasticities found in this study are lower than those obtained in other studies for India using aggregate data[6]. The results for income elasticities of demand confirm the results obtained in other studies performed for India using aggregate data. The values obtained in our study are lower than one, as expected, but higher than those obtained in similar studies for highly developed countries[7].

5. Summary and conclusions

The paper provides results of the estimation of three seasonal double logarithmic linear econometric models of electricity demand for urban India using household level micro data. The models are used to determine the responsiveness of electricity consumption to own price, income, price of substitutes and variables relating to demographic and geographic

[6] See Bose & Shukla (1999).
[7] See for instance D. Hawdon (1992), M. Filippini (1999).

characteristics of households, for three different seasons – summer, winter and monsoon. The estimated models demonstrate the importance of household and other geographical characteristics in determining electricity demand, something which is not possible using aggregate macro models alone.

The results show that the estimated equation is fairly stable over the three different seasons. However, a great degree of heterogeneity in household electricity demands at the individual household level is evident. The relatively high income elasticities of demand for electricity estimated in the paper confirm that with further economic development of the country, one can expect to see a rise in the electricity consumption of households.

The models provide estimates of income, own and cross price elasticities of electricity demand for urban India. As would be expected, the estimates for income elasticities show that electricity is a necessity. The seasonal analysis shows that demand is income inelastic in all three seasons and the elasticity is fairly constant across the seasons. In contrast, there appears to be considerable seasonal variation in own-price elasticities for electricity, with the price elasticity in summer being at least half that observed during the rest of the year. However, electricity is found to be price inelastic in all three models. The cross price elasticities between fuels show that electricity is complimentary to kerosene, that is, a rise in the kerosene price would result in a slight fall in electricity demand in all three seasons. Looking at cross price elasticities for LPG (liquid petroleum gas) it appears that although there is complementarity between electricity and LPG in the non-summer months, LPG is a substitute for electricity in the summer.

Generally, the results of the study as regards the own price elasticity show that a pricing policy alone will not be effective in curbing future household electricity demand in India. However, given that electricity tends to be consumed disproportionately by wealthier and better off segments of the urban population in India, the present method of subsidization is not efficient. The current policy of subsidisation implies that in effect a large proportion of the benefits are realised by the upper middle and higher income groups and therefore defeats the purpose of the subsidies.

In planning for the future, the government and electricity agencies need to be aware of the heterogeneity of electricity demand in India, not only in respect to regional variations but also in terms of distinctive household characteristics.

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