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Abstract

This study aimed to explore households' energy use pattern, and the impact of socio-economic characteristics on the choice and demand for energy sources at household level in Tamil Nadu. Probit function and QUAIDS models were employed in multistep procedure to estimate choice and quantity demanded with respect to changes in income, total fuel expenditure, price, and cross-price, with the help of national-level household survey data. The results of the study revealed that both rural and urban households follow fuel stacking as various kinds of fuel sources are used for different purposes. Prices of fuels, income, education, and regular salary earning capacity of households were found to be major determinants of fuel choice. Compared to 2004–2005, income and own-price elasticity of most fuels were found inelastic in 2011–2012. Firewood in urban region and kerosene in both regions were found inferior good and Giffen good, respectively, whereas electricity and Liquefied Petroleum Gas were normal goods in all regions in all periods. Cross-price elasticities showed no significant substitutability among the fuels in the state.

Keywords: energy, household, price, income, QUAIDS, choice and demand

1. Introduction

Energy fuel materials are inevitable components in the consumption baskets of a household. They are considered a critical indicator of socio-economic activity, national economic growth, and the environment (Jacobson, 2005). Clean, efficient, affordable, and reliable energy services are associated with reduction in poverty, health problems, gender inequality, environmental degradation, and indiscriminate use of natural resources (Alem, Beyene, Köhlin, & Mekonnen, 2016). Fuels can be of two types: (*a*) traditional fuels or solid fuels or higher greenhouse gas (GHG) emitters (e.g., biomass, firewood, charcoal, grass, straw, and animal waste); and (*b*) modern fuels or non-solid fuels or lower GHG emitters (e.g., Liquefied Petroleum Gas [LPG] and electricity).

Scholars argue that solid fuels are sources of secondary pollutants, such as acid rain and ozone, which are harmful to human respiratory systems (Sinha & Nag, 2011). Combustion of biomass and other solid fuels acts as a major source for emission of toxic contaminants, causes air pollution (Chakraborty, Mondal, & Datta, 2014), and leads to acute respiratory problems and death of young children (Murray, Lopez, & WHO, 1996; Smith, Mehta, & Maeusezahl-Feuz, 2004), chronic pulmonary disease, lung cancer, asthma, laryngeal cancer, tuberculosis, cardiovascular disease, pregnancy complication with stunted growth of baby, cataract, and blindness, when people continue to rely on biomass over a period (Sinha & Nag, 2011). Around 2.8 billion people are using solid fuels for cooking and heating, and 1.2 billion are using kerosene lamps for lighting (WHO, 2015). Women and children, in general, and poor households specifically, are highly exposed to smoke and air pollution and affected by chronic and acute respiratory infections (Dasgupta, Huq, Khaliquzzaman, Pandey, & Wheeler, 2006; Martin et al., 2013). WHO (2015) says that air pollution is responsible for pregnancy complication, stunted growth, and about 4.3 million premature deaths annually (50% of them being children below five years in underdeveloped countries). The use of dirty fuel sources is highly attributed not only with health problems to humans but also with deforestation, environmental degradation, and global warming (Bhatt, Rathore, Lemtur, & Sarkar, 2016; Bhattacharyya, 2015; Chambwera & Folmer, 2007; Cruz & Crnkovic, 2016; Dasgupta et al., 2006; Geist & Lambin, 2002; Kastner & Stern, 2015; Ramanathan & Carmichael, 2008; Reyes, Nelson, & Zerriffi, 2018; Zulu & Richardson, 2013).

The adoption of modern fuel sources by households has been identified as a measure of alleviating the detrimental effects on environmental, social, and human health by cooking and heating with dirty fuels (Malakar, 2018). In the last two decades, numerous projects and programmes have been introduced in India as well as the world, to encourage households to use modern fuels—which includes LPG, biogas, ethanol, and solar energy—to minimise indoor air pollution and mitigate global warming. For instance, China and India introduced the National Improved Stove Programme and National Programme for Improved Chulhas, respectively, in the early 1980s to minimise indoor air pollution (Amegah & Jaakkola, 2016). Securing safe and clean fuels for all people is one of the objectives of the Millennium and Sustainable Development Goals (Mensah & Adu, 2015). However, there is a lack of adoption of modern energy in India due to several factors, such as less awareness of dirty effects, partial accessibility, and poor affordability of modern fuels.

Security in safe and clean fuels among households is difficult unless there is a proper understanding of household behaviour in choice and demand with respect to changes in variations in socio-economic, demographic, and other household characteristics. The choice of energy dependency, particularly firewood sources, is vitally influenced through its physical availabilities, accessibilities, and socio-economic factors (e.g., income and wealth), demographic (e.g. family size, household composition, lifestyle and culture), geographic backgrounds (e.g., proximity to sources of modern and traditional fuels), and ethics of human attitudes (An, Lupi, Liu, Linderman, & Huang, 2002; Dovie, Witkowski, & Shackleton, 2004; Israel, 2002; Karekezi & Majoro, 2002).

Among Indian states, Government of Tamil Nadu, in 2007, introduced a series of programmes and projects, such as cooking gas connections and gas stoves for below poverty level (BPL) families, free of cost; electricity has been provided at a subsidised price over a couple of decades to secure clean fuels and discourage the use of solid fuels by households. Also, Tamil Nadu is among states with the highest users of LPG in the country. Thus, Tamil Nadu is on its way to reduce fuel dependency from pollution-causing sources. As a socially and economically developed state, Tamil Nadu is in need of more research and analysis on energy consumption pattern to evaluate how policy instruments work to alter households' fuel choice and demand.

A few studies have analysed and discussed the pattern of energy sector, both at macro and household levels in India (Filippini & Pachauri, 2004; Gundimeda and Köhlin, 2008; Mushtaq, Sood, & Peshin, 2014; Pachauri, 2004; Pachauri & Spreng, 2002, 2004; Pachauri, Mueller, Kemmler, & Spreng, 2004). But there have been no systematic studies which focus on regional or individual state levels as the energy use pattern varies across different regions, states, locations, and types of occupation of households. Manjula and Gopi (2017) tried to capture changes in energy use pattern across income groups and social categories in Tamil Nadu and Orissa, with the help of National Sample Survey Office (NSSO) household survey data for different years and to find out trends of energy use alone. The present study, therefore, aims to estimate the level of influence of major socio-economic characteristics on the choice of energy use and demand at the household level in both rural and urban Tamil Nadu.

The rest of the paper is organised as follows: Section 2 presents the data, methodology, and tools of analysis employed in the study. Section 3 presents the results of the study and discusses the results of the study. Section 4 summarises and concludes the overall study results.

2. Method

Data

In this study, we used unit-level consumer survey data on food and non-food expenditure collected by the NSSO in India for 2004–2005 and 2011–2012, to capture spatial and temporal impacts. This is a national survey with a sample size of over one lakh households in rural and urban regions. (For details of sampling procedure, see NSSO's *Household Consumption on Various Goods and Services in India* reports of respective years.) Among fuel sources at household level, we chose firewood, kerosene, LPG, and electricity, as these four fuels cover more than 80 per cent of total fuel expenditure. Price response of demand was obtained on the basis of unit values. The unit price for a fuel source was derived by dividing the value of fuel item by total quantity used by a respondent in a region. Price for a fuel item that was not used by any respondents in a region was given the average price of the corresponding region. Such a procedure to derive unit prices for food and fuels has been followed extensively in many food demand analysis studies (Deaton, 1997; Kedir, 2005).

Model Specification

Theory of Consumer Behaviour

Theory of consumer behaviour and demand for food and non-food commodities explain how rational consumers choose what to consume at given prices of goods and services and income level. Classical theory explains consumer demand as a problem of utility maximisation within a given budget constraint. This section presents the theoretical model for a household's energy demand derived from the utility maximisation principle (Sadoulet & de Janvry, 1995).

Underlying the theoretical model of Blundell (1988) and Baker, Blundell, and Micklewright (1989), utility obtained from fuels is due to quantity consumption of various types of fuels. Consider an individual consumer whose utility function for fuel demand is $u(q_1, q_2, \ldots q_n)$, where all q_s are the quantities of different fuels on which a consumption decision must be made. The amount of income which can be spent is y, imposing a budget constraint $p'q = y$, where p' is an n-dimensional row vector of prices. The consumer's objective function is to maximise utility with respect to q, subject to the budget constraint $p'q = y$. This can be rewritten as:

$$\underset{q,\lambda}{Max}\, u(q,z)+\lambda(y-p'q),$$

where λ is a Lagrange multiplier.

The solution to this maximisation problem is a set of n demand equations:

$$q_i = q_i(p,y,z), \qquad i=1,\ldots\ldots\ldots\ldots,n.$$

These n equations contain:

n income slopes $\frac{\partial q_i}{\partial y}$ or income elasticities $\eta = \frac{\partial q_i}{\partial y}\frac{y}{q_i}$, and

n^2 price slopes $\frac{\partial q_i}{\partial p_j}$ or price elasticities $E_{ij} = \frac{\partial q_i}{\partial p_j} \frac{p_j}{q_i}$

Goods can be categorised according to the signs and magnitudes of these elasticities as follows:

Categorisation with respect to income elasticity:

Normal good: $\eta_i > 0$ ($\eta_i > 1$ *luxury*; $0 < \eta_i < 1$ *necessity*)

Neutral good: $\eta_i = 0$

Inferior good: $\eta_i < 0$

Categorisation with respect to own-price elasticity:

Non-Giffen good: $E_{ii} < 0$ ($E_{ii} < -1$ *elastic*; $E_{ii} > -1$ *inelastic*)

Giffen good: $E_{ii} > 0$

Categorisation with respect to cross-price elasticity:

Substitutes: $E_{ij} > 0$

Complements: $E_{ij} < 0$

These parameters must satisfy the following constraints: (*a*) add up to total expenditure; (*b*) are homogeneous of degree zero in prices alone or jointly in prices and total expenditure; (*c*) have negative compensated own-price responses; and (*d*) exhibit symmetric compensated cross-price responses (Deaton & Muellbauer, 1980). As can be expected, testing the validity of this characterisation occupies a major place in empirical demand analysis. In this regard, it is common practice to specify functional forms (for utility or expenditure) that are flexible enough to lead to demands possessing the above properties, such that the relevant restrictions are statistically imposed and tested.

Empirical Model

This section describes the demand model adopted in this study. Consumer behaviour and demand for various food and non-food commodities have been estimated by applying popular demand models, such as Linear Logarithmic model (Cobb–Douglas function) (Narayanan, Chintagunta, & Miravete, 2007; Silk & Joutz, 1997), Linear Expenditure System (LES) derived by Stone (1954) and Almost Ideal

Demand System (AIDS) given by Deaton and Muellbauer (1980). Bollino and Violi (1990) developed the Generalised AIDS model by combining the LES and AIDS models. Upgraded versions of the AIDS model, such as linear approximate AIDS (LA/AIDS) and quadratic AIDS (QUAIDS) models, have been applied extensively to estimate the demand elasticities for food commodities and fuels (Lin & Liu, 2013; Tafere & Worku, 2012; Tafere, Taffesse, Tamiru, Tefera, & Paulos, 2010; Umanath, Vijayasarathi, Babu, & Baskar, 2016; Wang & Reed, 2013).

In this study, we used QUAIDS model as it allows non-linear Engel curves (Banks, Blundell, & Lewbel, 1997) and tests the restriction of homogeneity and symmetry through restriction of fixed parameters (Deaton & Muellbauer, 1980). We followed the two-step estimation procedure given by Shonkwiler and Yen (1999) to estimate the demand elasticities of income and price, as all households need not use all fuels, and consequently the data set has zero expenditure problem in the dependent variables. Accordingly, in the first stage, probit function was used to capture the choices of income allocation to different kinds of fuels that are available to households. In the second stage, the level of allocation of total fuel expenditure was captured by using the QUAIDS demand model. The estimation procedure used in the two stages was as follows.

The first step involves estimating a probit regression function to estimate the probability of using a particular energy source, and the function is expressed as follows:

$$d_{ih} = \theta_0 + \sum_j \theta_{ij} \ln p_j + \theta_x \ln x_h + \theta_1 HHS_h + \theta_2 RSE_h + \theta_3 E_h + \theta_4 DWU_h + \theta_5 OWL_h \\ + \theta_6 Age_h + \theta_7 SEX_h + \theta_8 FAFH_h + \theta_9 MPCE_h + \mu_i \qquad (1)$$

where d_{ih}=1 if the hth household uses ith energy source and 0 if the household does not; lnp_j' are the prices of Electricity, Firewood, LPG and Kerosene; x_h is total household expenditure on fuels; HHS, RSE, E, DWU, OWL, Age, SEX, FAFH, MPCE, EE denote household size, regular salary earners, education level, owning dwelling units, possessing land, age, gender of household head, having food away from home, monthly per capita expenditure, and total energy expenditure, respectively. From the estimated probit function, Cumulative Density Function (CDF) and Probability Density Function (PDF) were calculated and used as one of the independent variables in the subsequent demand model to avoid the sample selection bias that arises due to zero consumption problem among households.

The second step provides the estimated form of the QUAIDS with a set of constraints imposed (), which is represented as follows:

$$w_{ih} = \Phi(z_{ih} \hat{\theta}_i)\left\{\alpha_i + \sum_{j=1}^{n}\gamma_{ij}\ln p_j + \beta_i \ln\left[\frac{x_h}{a(p)}\right] + \frac{\lambda_i}{b(p)}\left\{\ln\left[\frac{x_h}{a(p)}\right]\right\}^2 + \tau_i \hat{e}_h\right\} + \delta_i \phi(z'_{ih} \hat{\theta}_i) + \xi_{ih} \quad (2)$$

where $w_{ih} = \left(\frac{p_i q_i}{x}\right)$ the i^th^ energy expenditure share for consumer h; p_i=the price of good i; q_i= quantity of energy i; x=total energy expenditure; $\hat{e}_h$ is the residual from the total expenditure regression function against the set of independent variables to solve the endogeneity problem of total expenditure variable in the estimation of the QUAIDS model; and $\Phi(z_{ih} \hat{\theta}_i)$ and $\delta_i \phi(z'_{ih} \hat{\theta}_i)$ are CDF and PDF, respectively, obtained from the first-stage probit regression. The parameters of the QUAIDS model are estimated using Poi's Stata routine (Poi, 2008). Adjustments are made to the original routine to include additional control variables in order to capture endogeneity and selectivity problems as appropriate.

Dynamics in Energy Consumption in Tamil Nadu

In 2004–2005, rural households in Tamil Nadu used, on average in a month, 21.64 kg solid fuels, including firewood, charcoal, coal, and coke, for cooking and lighting (Table 1). But this declined by 10.81 per cent in 2011–2012. Kerosene use too declined, by 13 per cent during the same period. In contrast, LPG and electricity consumption increased by 75 per cent and 55 per cent, respectively, among rural households. Compared to rural households, urban households were already consuming lesser quantities of firewood and kerosene, and their switch from solid fuel and kerosene to other sources has been rapid. Urban households reduced their solid fuels and kerosene usage by more than 30 per cent. All these indicate that rural and urban households are switching from dirty fuels to clean fuels. Specifically, the progress is more rapid in rural areas because rural households are relatively backward in the energy ladder.

Table 1. Quantity Consumption of Different Types of Fuel Sources

Variable	Rural		Urban	
	2004–05	2011–12	2004–05	2011–12
Electricity (units)	5.667	8.928	20.008	25.869
Firewood (kg)	21.637	19.298	6.812	4.740
LPG (kg)	0.216	0.378	1.608	1.928
Kerosene (l)	0.619	0.535	0.620	0.397

The expenditure on different fuels is presented in Table 2. Rural households' energy expenditure was less than of urban households in 2004–2005 and 2011–2012. Interestingly, both rural and urban households allocated almost equal proportion (8.92 per cent) of their total income on accessing fuels in 2004–2005. This proportion decreased to less than 6 per cent in both regions in 2011–2012. Among energy sources, firewood occupied a larger proportion of total expenditure in

Table 2. Expenditure and Share of Different Types of Fuel Sources

(Rupees)

Variable	Rural		Urban	
	2004–05	2011–12	2004–05	2011–12
Electricity	19.30 (1.61)	18.24 (1.08)	65.85 (3.64)	53.78 (2.05)
Firewood	56.59 (4.72)	42.18 (2.49)	14.85 (0.82)	9.78 (0.37)
LPG	14.84 (1.24)	26.63 (1.57)	58.71 (3.25)	61.04 (2.33)
Kerosene	14.20 (1.18)	9.63 (0.57)	19.90 (1.1)	12.39 (0.47)
Other fuels	2.14 (0.18)	2.54 (0.15)	1.98 (0.11)	2.65 (0.1)
Total energy value	107.07 (8.92)	99.22 (5.86)	161.29 (8.92)	139.64 (5.33)

Note: Figures in parentheses are in percentage.

rural areas, whereas electricity and LPG usage were found higher in urban areas in both periods. Expenditure share of LPG increased only in rural areas, while the shares of all other fuels decreased over the period.

Figures 1 to 8 present socio-economic profiles of Tamil Nadu households towards the choice of fuel usage. The average consumption of electricity of households shows an increasing trend across income groups in both rural and urban regions. High-income households are the biggest household consumers of electricity, with average consumption of more than 50 units per month—this is almost 45 per cent more than other income households in urban regions and 55 per cent more than rural households. Firewood consumption decreased across income groups in urban areas; in rural region, middle-income households consumed more than low- and high-income groups. LPG usage, despite larger differences in quantity consumption across rural and urban regions, increased across income groups. Although kerosene usage varied slightly across income groups in rural areas, significant reduction in kerosene consumption was observed in 2011–2012. In contrast, larger differences in kerosene use was found across income classes and time in urban region. Female-headed households in rural and urban regions are bigger consumers of electricity, firewood, and kerosene, whereas there is a considerable difference between male- and female-headed households with respect to the use of LPG. Households having regular salary earners consumed more electricity and LPG in both regions, whereas they used less of firewood and kerosene. In urban region, more units of electricity were consumed by households owning dwelling units, while in rural region, per capita consumption was higher among non-owning households. Surprisingly, small families consumed more electricity, LPG, and kerosene than larger family-size groups in rural and urban regions. Compared to households with illiterates, households having college-level education used more of electricity and LPG; households with lower level of education consumed greater quantities of firewood and kerosene. These explain how the quantity consumed of different fuels varies across income groups, location of residents, and other household-level characteristics.

Figure 1. Income-wise Per Capita Consumption of Different Fuels in Tamil Nadu

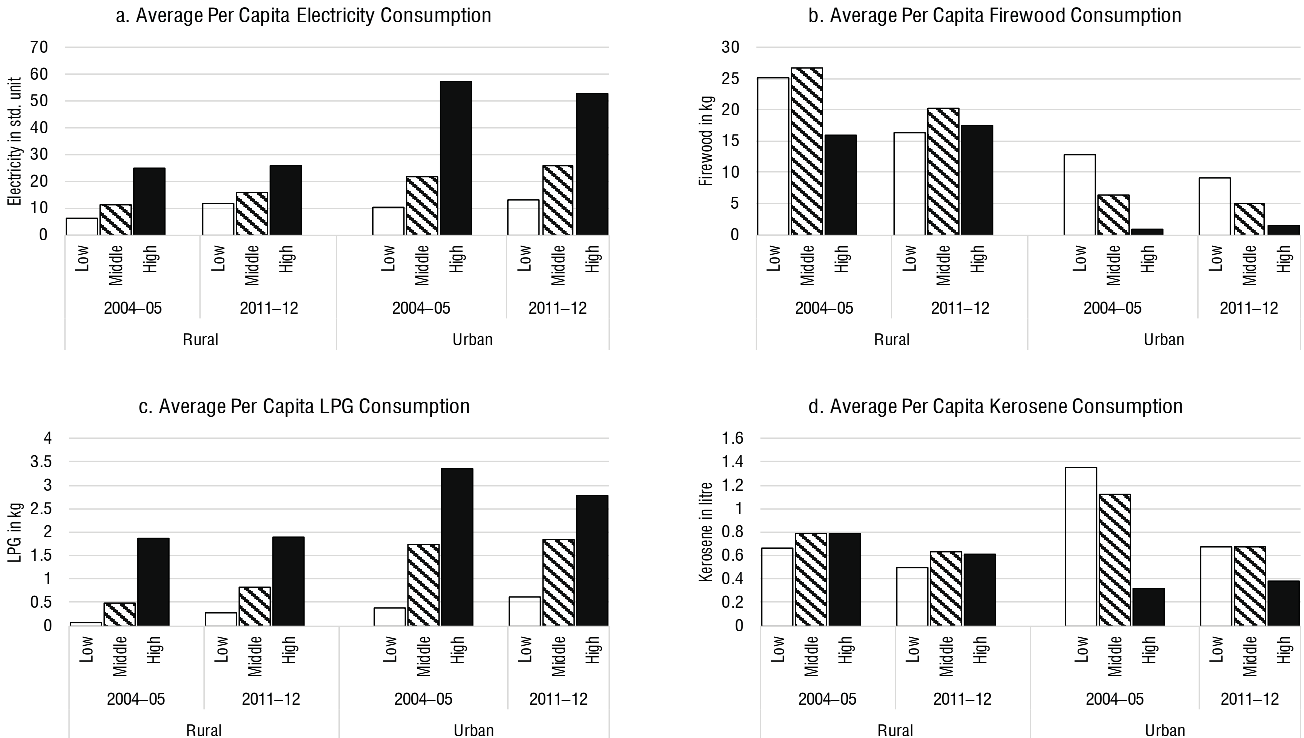


Figure 2. Gender-wise Per Capita Consumption of Different Fuels in Tamil Nadu

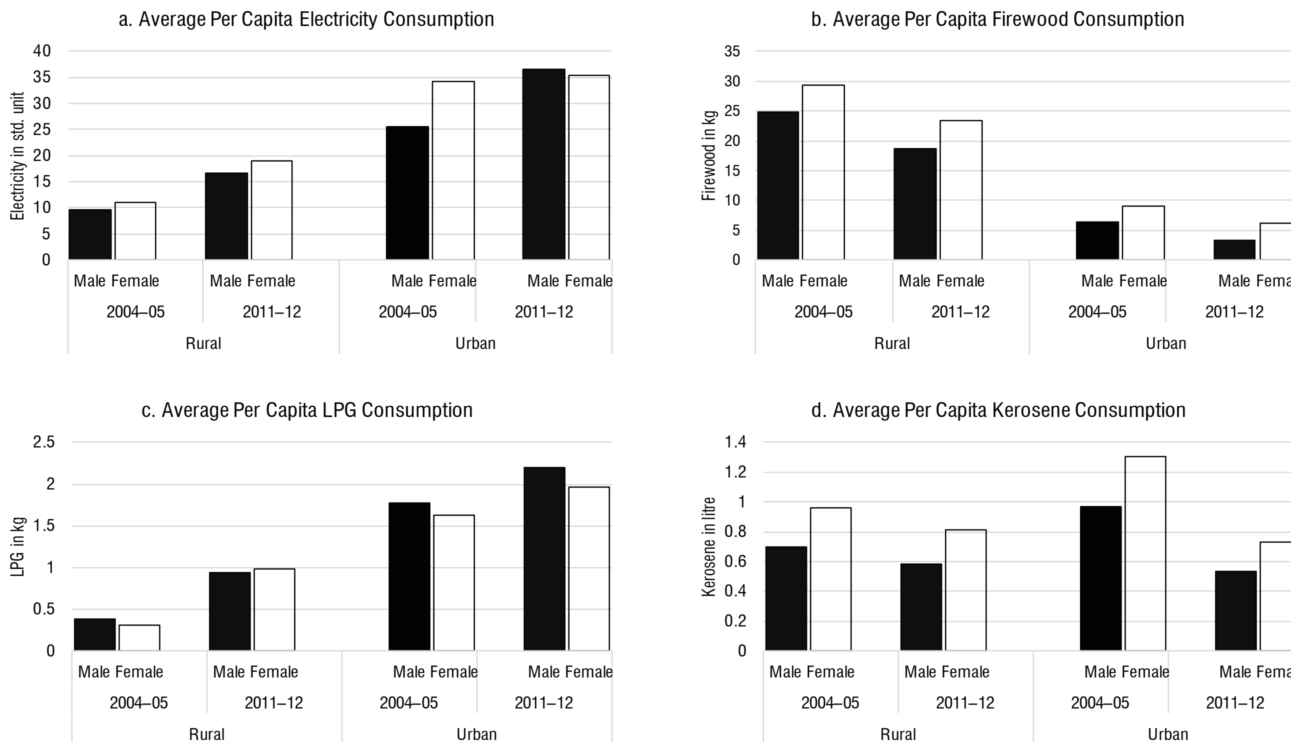


Figure 3. Salary-wise Per Capita Consumption of Different Fuels in Tamil Nadu

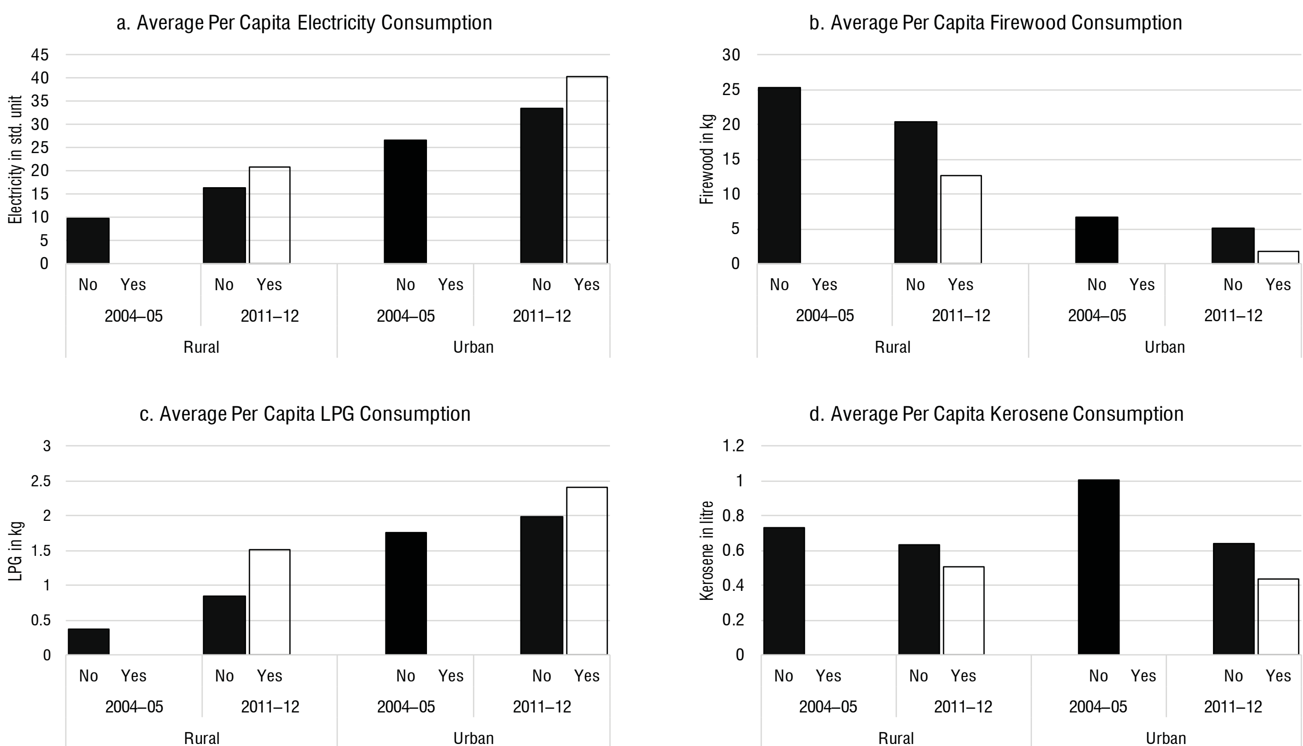


Figure 4. Dwelling unit–wise Per Capita Consumption of Different Fuels in Tamil Nadu

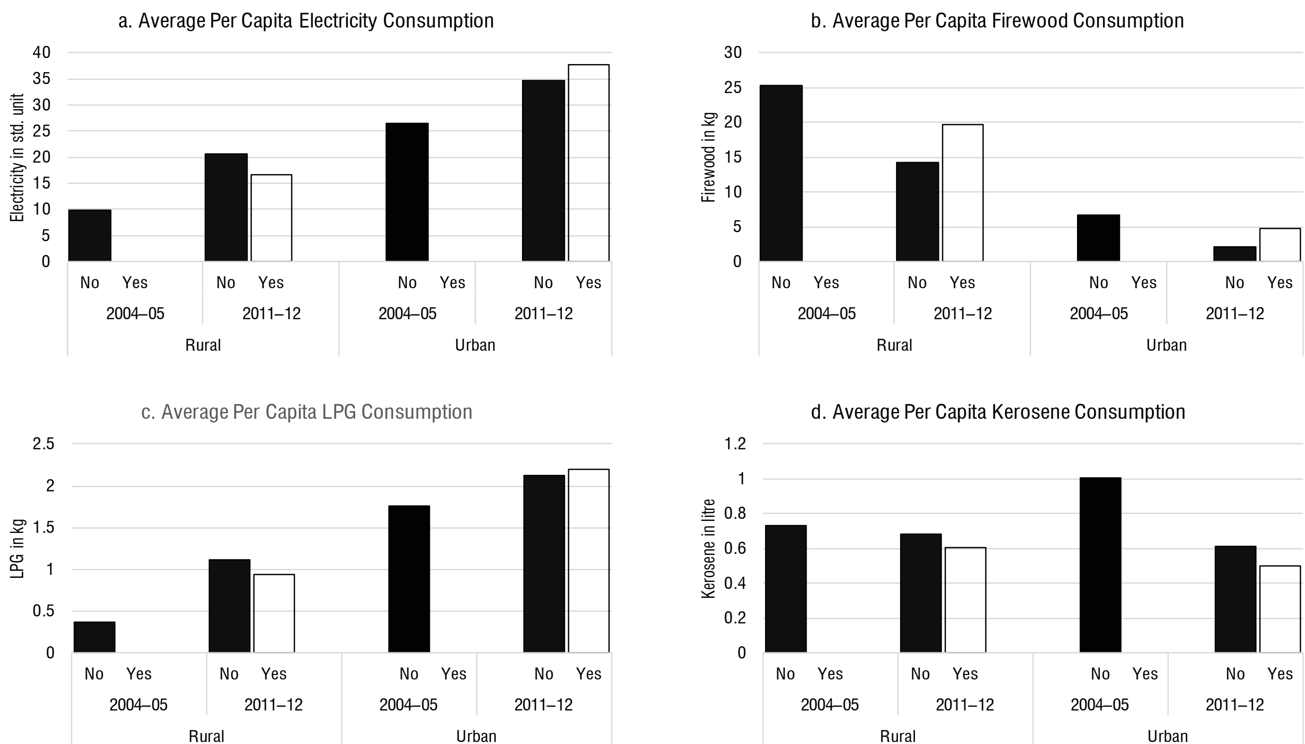


Figure 5. Land-wise Per Capita Consumption of Different Fuels in Tamil Nadu

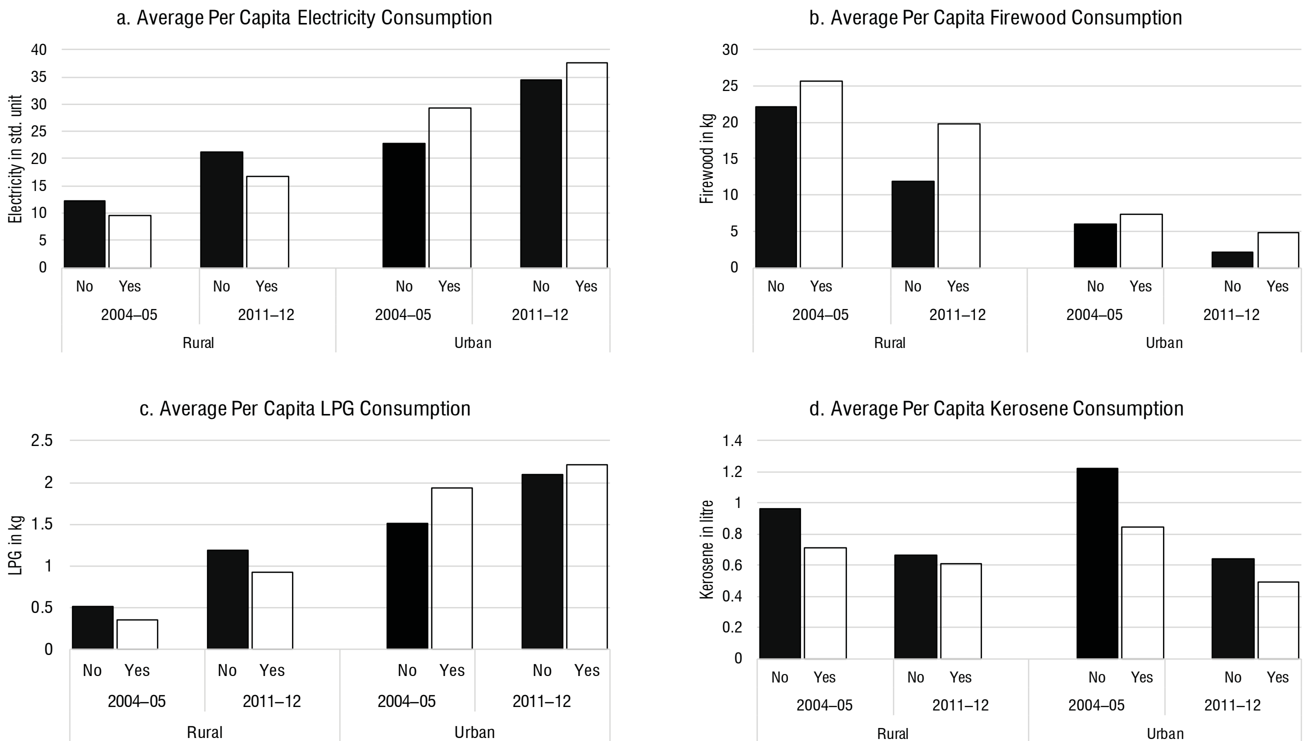


Figure 6. Household size–wise Per Capita Consumption of Different Fuels in Tamil Nadu

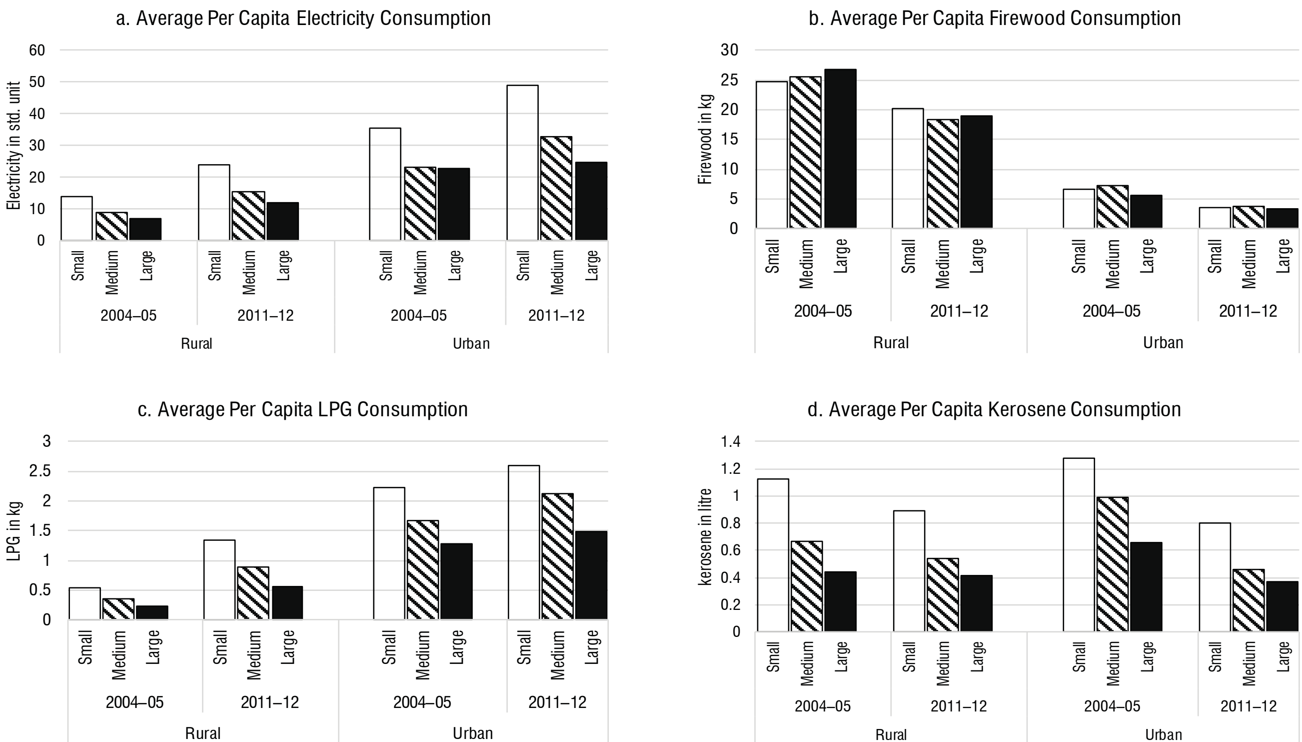


Figure 7. Age-wise Per Capita Consumption of Different Fuels in Tamil Nadu

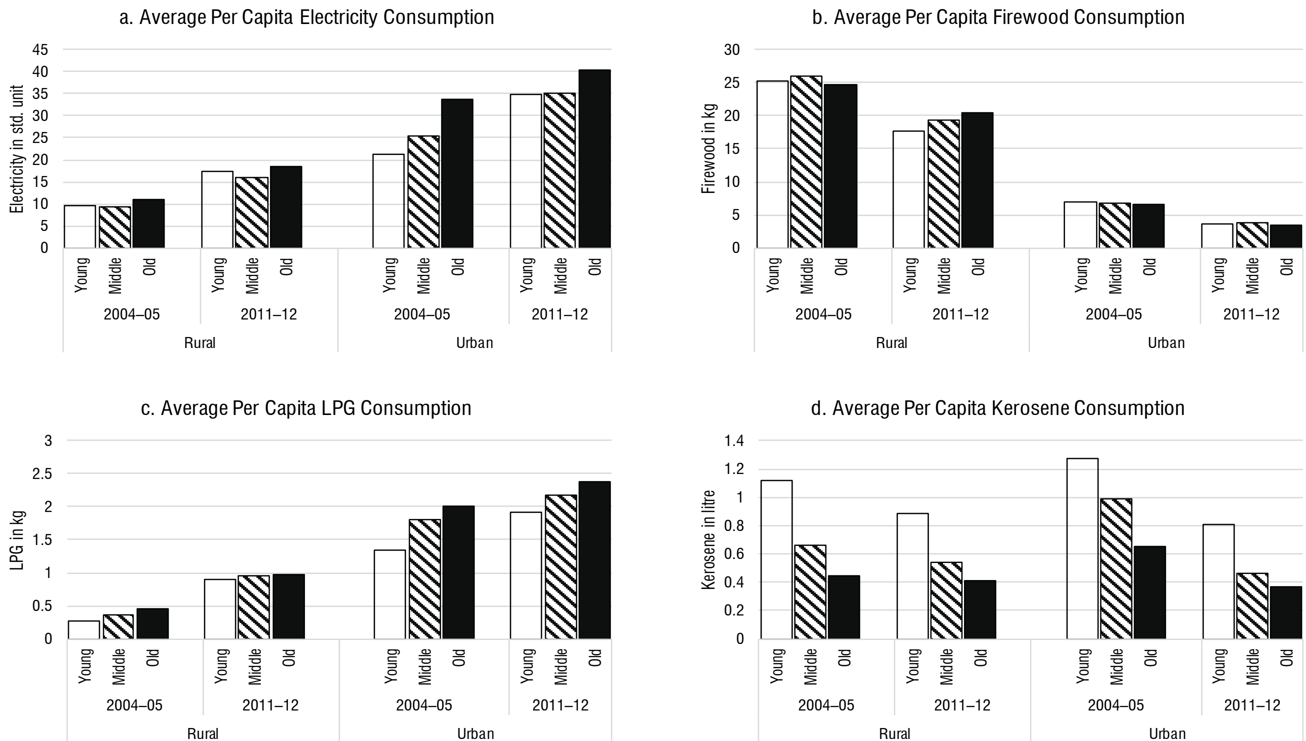
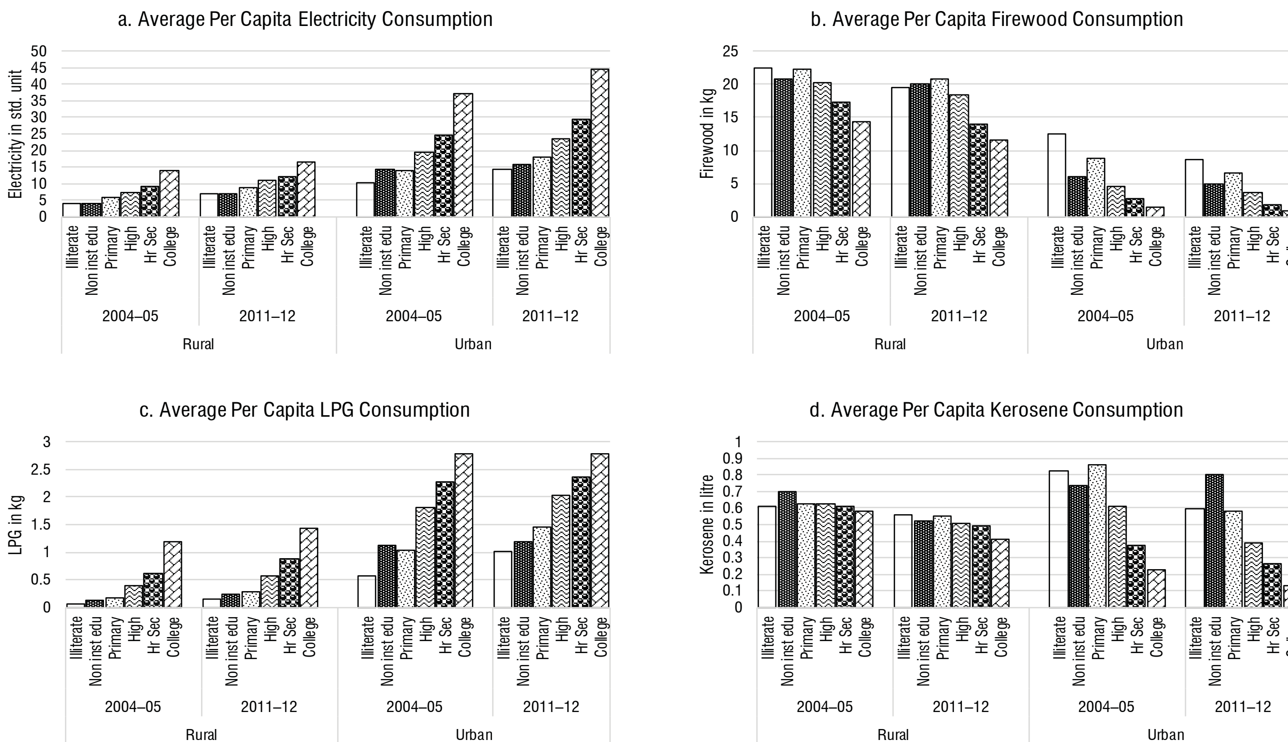


Figure 8. Education-wise Per Capita Consumption of Different Fuels in Tamil Nadu



3. Results and Discussion

Probability of Energy Choices Among Households

Probit function was estimated for each fuel to estimate the choice probability of particular energy in the first step. According to Shonkwiler and Yen's procedure, the dependent variable is a dichotomous variable—which takes the value 1 if the household uses a particular energy product and zero value if the household does not use—and was regressed against independent variables of prices of the fuels, total expenditure on all fuels used, and socio-economic characteristics, such as age, gender, education of the household head, presence of regular salary earners, land ownership, dwelling unit, HHS, per capita income, and habit of taking food away from home.

The estimated probit functions for rural and urban in 2004–2005 and 2011–2012 are given in Appendix A (Tables A1, A2, A3, and A4). Estimates of the total energy expenditure for electricity choice function in both regions in both times are positively significant, indicating that as total energy expenditure increases, households are more likely to increase electricity use in Tamil Nadu. A similar kind of impact is observed with respect to LPG use. In contrast, in urban region in 2011–2012 (compared with 2004–2005), when total energy expenditure was more, households were less likely to use firewood and more likely to use kerosene. Per capita income has significant and positive influence on the choice of firewood, LPG, and kerosene. In rural region in 2004–2005, the age of the household head has significant positive impact on the choice of firewood and kerosene and negative impact on the choice of electricity; this indicates that energy choice is becoming independent of age of household head. Households with higher level of education or presence of regular salary earners are more likely to use electricity and LPG, and less probable to use firewood or kerosene. If the family size is large, the probability of using LPG increases at all levels of households and all times. All these results reveal that socio-economic characteristics of households significantly influence the choice and probability of using different kinds and quality of fuels in Tamil Nadu.

Estimation of QUAIDS Model

The QUAIDS demand model was used to estimate the own-price, cross-price and income elasticities of demand for different types of fuels. Generally, QUAIDS demand model is estimated as a system of equations. Here, we took four equations for four fuels, namely, electricity, firewood, LPG, and kerosene. Budget share of each energy source was taken as the dependent variable for the corresponding demand equation, and unit prices for all energy products, total expenditure, and square of total expenditure were taken as independent variables. In addition, error terms derived from the regression of total expenditure against independent variables and PDF obtained from the estimation of probit function for each product were also taken as independent variables in the demand equations, to avoid the problem of endogeneity of total expenditure variable and presence of zero consumption in the dependent variables, respectively.

The QUAIDS estimates for rural and urban for each period (2004–2005 and 2011–2012) are presented in Appendix B (Tables B1 and B2, respectively). Almost 76 per cent of estimated coefficients of price and income variables were statistically significant. Apart from income and price variables, the coefficients of all the error terms (of each energy share equation) were statistically significant, indicating strong evidence for the adjustment of endogeneity problem of total energy expenditure. Similarly, PDF in all the energy share equations, except kerosene equations in 2011–2012 in rural and urban regions, were statistically significant, confirming that adjustments were made to control the zero observation problems with dependent variables.

Expenditure and Income Elasticities

The estimated expenditure and income elasticities (For equations, see Appendices C and D) of fuels in rural and urban Tamil Nadu for two different periods (2004–2005 and 2011–2012) are presented in Table 3. Expenditure and income elasticities enable us to identify whether the fuels are necessity, luxury, normal, or inferior products. Both income and expenditure elasticities for all fuels are positively significant at 1 per cent level, except firewood with negative income elasticity in urban regions in both periods. Firewood has negative income and expenditure

Table 3. Expenditure Elasticity of Different Fuels in Tamil Nadu

Fuel type	Rural				Urban			
	2004		2011		2004		2011	
	Expenditure	Income	Expenditure	Income	Expenditure	Income	Expenditure	Income
Electricity	1.183*** (0.183)	0.651*** (0.006)	1.279*** (0.271)	0.714*** (0.007)	1.671*** (0.15)	0.887*** (0.008)	1.404*** (0.239)	0.76*** (0.007)
Firewood	0.702*** (0.131)	0.386*** (0.004)	0.416*** (0.09)	0.232*** (0.002)	–0.744*** (0.164)	0.395*** (0.004)	–0.671*** (0.207)	–0.363*** (0.003)
LPG	2.124*** (0.262)	1.168*** (0.011)	1.584*** (0.332)	0.885*** (0.009)	1.39*** (0.278)	0.739*** (0.007)	1.192*** (0.212)	0.645*** (0.006)
Kerosene	0.919*** (0.154)	0.505*** (0.005)	0.918** (0.404)	0.513*** (0.005)	0.851*** (0.281)	0.452*** (0.004)	0.696*** (0.254)	0.377*** (0.004)

Notes: *** Significant at 1% level, ** Significant at 5% level. Figures in parentheses indicate standard error.

elasticities of demand on the average of whole samples in urban regions in both periods. Thus, firewood has become an inferior good in urban Tamil Nadu. Moreover, both income and expenditure elasticities were less than one for firewood and kerosene among rural and urban households, indicating that these fuels are not luxury products. Compared to kerosene and firewood, which are considered as dirty fuels for cooking and lighting, the income elasticity and expenditure elasticity for electricity and LPG are higher to some extent in both regions in both periods. For instance, the study results indicate that 1 per cent change in income would result in 0.71 per cent and 0.88 per cent increases in quantity consumption of electricity and LPG, respectively; this is higher than for firewood (0.23 per cent) and kerosene (0.51 per cent). Interestingly, the income elasticity of electricity has increased slightly from the first period to the second period in rural region, while there is a declining trend for all other fuels in both rural and urban regions. It is in line with the results of a few previous studies, which found a small and negative, or insignificant, income elasticity of firewood, and higher income elasticity for electricity and LPG (Cooke, Köhlin, & Hyde, 2008; Gundimeda & Köhlin, 2008; Hyde, Köhlin, & Amacher, 2000; Macauley, Naimuddin, Agarwal, & Dunkerley, 1989).

Own-price Elasticity

Price elasticity of demand is used to measure how households or consumers are responsive to changes in the prices of goods. Uncompensated own-price elasticity of energy demand describes the proportionate changes in quantity demanded of a particular fuel with respect to proportionate changes in the price of the respective fuel, for which no compensation is made in terms of changes in either price or income. Compensated price elasticity of energy demand represents the proportionate changes in quantity demanded of the particular fuel with respect to proportionate changes in the price of the respective fuel, which is compensated by changes in price (substitution effect) to retain the consumer at the same level of satisfaction. Once the allowance for price compensated to total changes in the quantity demanded of the uncompensated is made, the remaining is income effect—that is, substitution effect plus income effect is equal to the total price effect.

Table 4 presents own-price elasticity of all fuels under compensated

Table 4. Uncompensated and Compensated Own-price Elasticities of Different Fuels in Tamil Nadu

Fuel type	Rural				Urban			
	2004		2011		2004		2011	
	UC	C	UC	C	UC	C	UC	C
Electricity	–0.332*** (0.094)	–0.107^{NS} (0.072)	–0.431*** (0.11)	–0.159^{NS} (0.141)	–0.591*** (0.042)	–0.027^{NS} (0.061)	–0.362*** (0.097)	0.126^{NS} (0.168)
Firewood	–0.605*** (0.09)	–0.223*** (0.047)	–0.845*** (0.072)	–0.685*** (0.077)	–1.084*** (0.197)	–1.218*** (0.198)	–0.709^{NS} (0.44)	–0.786* (0.442)
LPG	–0.781^{NS} (0.5)	–0.518^{NS} (0.483)	–1.012*** (0.326)	–0.539** (0.268)	–1.135*** (0.299)	–0.722*** (0.238)	–0.617* (0.349)	–0.097^{NS} (0.278)
Kerosene	0.419^{NS} (0.326)	0.549* (0.327)	0.771* (0.448)	0.866* (0.457)	0.492** (0.229)	0.649*** (0.243)	1.705*** (0.454)	1.775*** (0.447)

Notes: UC = Uncompensated, C = Compensated. *** Significant at 1% level, ** Significant at 5% level, * Significant at 10% level, NS = Non-significant. Figures in parentheses indicate standard error.

and uncompensated settings. Uncompensated price elasticities should be interpreted as conditional elasticities, where it is assumed that relative price changes within fuels do not affect the real expenditure on energy sources. As expected, the own-price elasticity of electricity is negatively significant in both rural and urban regions in both periods. Demand for electricity is less responsive to changes in the price of its own as all the uncompensated own-price elasticity coefficients for electricity are less than one, indicating that households in Tamil Nadu hardly respond to higher price through demand management or substitution of other fuels. In other words, as the price of electricity falls by 10 per cent, the demand for electricity would increase in rural region by 3.32 per cent in 2004–2005 and 4.31 per cent in 2011–2012, and by 5.91 per cent and 3.61 per cent in urban region in the respective years. Of this total increase in electricity demand, 1.07 per cent, 1.59 per cent, 0.27 per cent, and 1.26 per cent, respectively, are due to substitution effect as compensated price elasticity suggests. The income effect of the decreased price accounts for the remaining (i.e., difference between price effect and substitution effect)—2.56 per cent (rural 2004–2005), 136.51 per cent (rural 2011–2012), 9.44 per cent (urban 2004–2005), and 31.50 per cent (urban 2011–2012)—increase in electricity demand due to increase in real income, despite the unchanged absolute amount of money income. In addition, since the compensated price elasticity for electricity is less than the uncompensated price elasticity, we interpret that price response of electricity demand largely depends on income. Therefore, when income is unchanged, the household's electricity demand is less responsive to price changes.

A similar response among the households of rural Tamil Nadu was observed with respect to firewood demand. However, in urban areas, demand responsiveness for firewood has changed from elastic (in 2004–2005) to inelastic (in 2011–2012). The income effect is negative for urban households in both periods, confirming that firewood is treated as an inferior good in urban areas. Moreover, as firewood is an inferior good in urban region, the total price effect is offset by the negative income effect and reflected in the uncompensated price elasticity. Compensated price elasticity of firewood is less than uncompensated price elasticity in rural areas and more than in urban areas, indicating that price response of firewood demand largely depends on own price in urban and on income in rural areas. In this situation, in rural areas, policies that generate income and employment, and in urban areas, price policy measures, would be the viable policy interventions to reduce the quantity of consumption of firewood in Tamil Nadu.

Regarding LPG, there is no significant response from rural households in 2004–2005, but it is highly responsive in 2011–2012 as LPG price changes, while the response of urban households has changed from elastic to inelastic during the same period. This indicates that the availability and accessibility of LPG in urban was more than in rural region. The income effect on LPG demand is positive in rural and urban regions. Also, compared to the other fuels, the income effect of changes in price is quite higher for LPG in 2011–2012, indicating that changes in the price of LPG would have a larger effect on real income among all the households, irrespective of geographical location. Manjula and Gopi (2017) stated that accessing clean fuels like LPG remained a challenge even in a state like Tamil Nadu. They also indicated that existing policy measures have not been effective and have not resulted in equitable access to clean fuels. Hence, the efficient implementation of price policy measures would lead the state towards clean energy consumption, as changes in the price of LPG have had a greater effect on real income.

Kerosene has positive price elasticity in rural and urban regions in both periods. This positive effect of own price on kerosene demand is not in line with the economic theory of law of demand. On the other hand, there is a negative income effect in both regions. Since the income effect of kerosene is negative, kerosene is also supposed to be an inferior good. Moreover, since the compensated price elasticity of kerosene is more than the uncompensated elasticity, a fall in the price of kerosene would have a greater effect on real income, followed by increased demand for kerosene. The following two observations in Tamil Nadu may be the reasons for this Giffen effect: first, over the years, kerosene has been supplied to households through fair price shops under the public distribution system at a subsidised price; second, kerosene is treated as an intermediate energy source in the energy ladder, which helps in fuel transmission from dirty solid fuels to clean and safe fuels, such as LPG and electricity.

Cross-price Elasticity

Cross-price elasticity for different fuels measures the responsiveness of changes in demand for an energy source with respect to changes in the price of another energy source. If cross-price elasticity is negative, then the fuels are called complements; if cross-price elasticity is positive, the fuels are said to be substitutes.

Table 5 and Table 6 provide, respectively, the estimated compensated and uncompensated cross-price elasticities. In this study, attention is given majorly to compensated cross-price elasticities, to identify whether the fuels are complements, substitutes, or independent, as compensated elasticity represents the pure effects (i.e., only substitution effect). For normal goods, the Hicksian own-price elasticities are, in absolute terms, smaller than the Marshallian ones. As per Table 6, all the compensated own-price elasticities are less than the uncompensated own-price elasticities. The Hicksian elasticities show asymmetric cross-price elasticity for most fuels, indicating that the fuels are simultaneously treated as substitutes and complements to each other. Accordingly, increased price of firewood, LPG, and kerosene increased the quantity demand for electricity in both periods. This suggests that households in Tamil Nadu use more quantity of electricity as prices of other fuels go up. However, increased price of electricity has a complementary effect on the quantity demanded of LPG and kerosene in urban region, and only on LPG in rural region. This asymmetric nature may be because electricity is majorly used for activities other than cooking, while LPG and kerosene are used only for cooking.

Higher LPG price increased the quantity demand of firewood in rural region in 2004–2005, whereas increased price of firewood reduced the demand for LPG in the same period. This asymmetric nature may be due to easy availability of firewood and inaccessibility of LPG in rural areas. The same pattern has not continued in 2011–2012—firewood price has not significantly influenced LPG consumption. In urban areas, increased price of LPG did not have a significant impact on firewood demand in 2004–2005 or 2011–2012, but increased price of firewood led to higher demand for LPG in 2004–2005. Kerosene has a significant, symmetric, complementary relationship with firewood only in urban region. A few studies have proven empirically the existence of asymmetric cross-price elasticities. Allenby and Rossi (1991) stated that

Table 5. Uncompensated Cross-price Elasticity of Different Fuels in Tamil Nadu

		Rural				Urban			
		Electricity	Fuelwood	LPG	Kerosene	Electricity	Fuelwood	LPG	Kerosene
2004–05	Electricity	–0.332*** (0.094)	–0.076^{NS} (0.055)	–14.28*** (3.551)	–0.623^{NS} (0.949)	–0.591*** (0.042)	0.353*** (0.113)	–6.433*** (0.995)	–3.283*** (0.9)
	Firewood	–0.417*** (0.153)	–0.605*** (0.09)	–5.972** (2.588)	–3.777*** (1.133)	–0.228*** (0.08)	–1.084*** (0.197)	6.996*** (2.559)	–2.126* (1.285)
	LPG	–0.018*** (0.005)	0.018*** (0.006)	–0.781^{NS} (0.5)	–0.379*** (0.144)	–0.055*** (0.011)	0.186*** (0.015)	–1.135*** (0.299)	–0.388** (0.18)
	Kerosene	0.005^{NS} (0.011)	–0.041*** (0.009)	–0.597^{NS} (0.751)	0.419^{NS} (0.326)	0.003^{NS} (0.009)	–0.129*** (0.02)	–0.631** (0.326)	0.492** (0.229)
2011–12	Electricity	–0.431*** (0.11)	0.001^{NS} (0.122)	–9.494*** (2.255)	–1.606^{NS} (2.306)	–0.362*** (0.097)	0.079^{NS} (0.457)	–9.049*** (2.168)	–6.705** (3.451)
	Firewood	–0.062^{NS} (0.096)	–0.845*** (0.072)	0.796^{NS} (3.463)	–2.88^{NS} (1.98)	–0.06^{NS} (0.044)	–0.709^{NS} (0.44)	1.581 ^{NS} (1.266)	–3.398** (1.374)
	LPG	–0.027*** (0.009)	0.063*** (0.011)	–1.012*** (0.326)	–0.592** (0.284)	–0.037^{NS} (0.015)	0.231*** (0.04)	–0.617* (0.349)	–0.848*** (0.31)
	Kerosene	0^{NS} (0.007)	–0.044*** (0.012)	–0.512^{NS} (0.374)	0.771* (0.448)	–0.006^{NS} (0.005)	–0.139*** (0.051)	–0.534** (0.25)	1.705*** (0.454)

Notes: *** Significant at 1% level, ** Significant at 5% level, * Significant at 10% level, NS = Non-significant. Figures in parentheses indicate standard error.

Table 6. Compensated Cross-price Elasticity of Different Fuels in Tamil Nadu

		Rural				Urban			
		Electricity	Firewood	LPG	Kerosene	Electricity	Firewood	LPG	Kerosene
2004–05	Electricity	–0.107^{NS} (0.072)	0.057^{NS} (0.043)	–13.876*** (3.539)	–0.448^{NS} (0.938)	–0.027^{NS} (0.061)	0.102^{NS} (0.106)	–5.963*** (1.001)	–2.995*** (0.876)
	Firewood	0.227*** (0.073)	–0.223*** (0.047)	–4.815** (2.578)	–3.277*** (1.087)	0.074^{NS} (0.064)	–1.218*** (0.198)	7.247*** (2.52)	–1.972^{NS} (1.268)
	LPG	0.128*** (0.022)	0.104*** (0.011)	–0.518^{NS} (0.483)	–0.265* (0.144)	0.441*** (0.036)	–0.035^{NS} (0.045)	–0.722*** (0.238)	–0.136^{NS} (0.134)
	Kerosene	0.173*** (0.036)	0.058** (0.027)	–0.296^{NS} (0.759)	0.549* (0.327)	0.311*** (0.035)	–0.266*** (0.032)	–0.375 (0.359)	0.649*** (0.243)
2011–12	Electricity	–0.159^{NS} (0.141)	0.09^{NS} (0.12)	–9.157*** (2.304)	–1.41^{NS} (2.354)	0.126^{NS} (0.168)	–0.155^{NS} (0.44)	–8.634*** (2.227)	–6.463* (3.446)
	Firewood	0.43*** (0.048)	–0.685*** (0.077)	1.406^{NS} (3.351)	–2.526^{NS} (1.848)	0.102*** (0.038)	–0.786* (0.442)	1.719^{NS} (1.249)	–3.317** (1.368)
	LPG	0.354*** (0.074)	0.187*** (0.021)	–0.539** (0.268)	–0.318^{NS} (0.239)	0.576*** (0.091)	–0.062^{NS} (0.079)	–0.097^{NS} (0.278)	–0.544* (0.318)
	Kerosene	0.132*** (0.034)	–0.001^{NS} (0.016)	–0.348^{NS} (0.394)	0.866* (0.457)	0.135*** (0.028)	–0.206*** (0.056)	–0.414^{NS} (0.263)	1.775*** (0.447)

Notes: *** Significant at 1% level, ** Significant at 5% level, * Significant at 10% level, NS = Non-significant. Figures in parentheses indicate standard error.

sign asymmetry in cross-price elasticities may exist due to difference in the quality of items. They argued that although two items are substitutes, the difference in income effects between the high-quality and low-quality items results in sign asymmetry of cross-price elasticity. Bonfrer, Berndt, and Silk (2006) also demonstrated the same—that sign and magnitude asymmetry in cross-price elasticities is theoretically and empirically possible. Such asymmetry can be explained by the relative magnitude of share-weighted income elasticity, the observed Hicksian compensated rate of substitution, and the category demand effect. Mensah and Adu (2015) too observed such kind of asymmetric cross-price elasticity between LPG and firewood and interpreted that the quality difference between these two fuels, especially in terms of fuel efficiency and associated emission from combustion, is the main reason for the existence of asymmetric cross-price elasticity between these two fuels.

4. Conclusion

The study aimed to analyse the dynamics in the response of households on the use of different fuels like electricity, firewood, LPG, and kerosene with respect to changes in the income and prices of the fuels in Tamil Nadu. The results reveal that households in Tamil Nadu follow fuel stacking behaviour (i.e., households spend their income on different fuels simultaneously) rather than switching, probably for different purposes and technologies. In addition, rural people shifted their energy use pattern from firewood to electricity and LPG by 2011–2012. Urban households have been continuing their dependency on electricity and LPG since 2004–2005. Prices of fuels, per capita income, household head's higher education level, and presence of regular salary earner are the major factors affecting fuel choice.

Demand that is income elastic for most fuels explains the fuel stacking behaviour among households in Tamil Nadu. So, addressing the lacunae in existing policy measures and developing other appropriate policy options are required to switch households from solid fuels to clean fuels, particularly in rural Tamil Nadu. Rural households still use greater quantity of solid fuels for cooking and other heating activities, to save the use of LPG and associated cost, even though the price of

LPG is subsidised. Electricity and LPG were found as normal goods, whereas firewood was observed as an inferior good in urban regions and kerosene as a Giffen good in both rural and urban regions. On the other hand, estimates of cross-price elasticity showed asymmetric and weak substitutability between the fuels. It underlines the need for improvement in existing policy interventions for increasing the availability, accessibility, and affordability of electricity and LPG to all households. For instance, since per capita income was found significant on the adoption of clean fuels, further improvement in income level can be expected to increase the choice of clean fuels, such as LPG and electricity.

Since the study was constrained by lack of data on technological options in types of cooking and heating apparatuses, stoves, and utensils, the impact of technology on energy consumption pattern and choice was not considered here. Also, household-level data for energy use and expenditure are available only till 2011–2012. We suggest that future research may concentrate on studying the role of technology in replacing dirty fuels (in households) with fuels which are safe, clean, and eco-friendly.

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Appendix A

Table A1. Results of Estimated Probit Function for Electricity

	Rural		Urban	
	2004–05	2011–12	2004–05	2011–12
Total energy expenditure	0.201***	0.039**	0.1***	0.033**
Price of electricity	–0.217***	–0.055***	–0.088***	–0.029***
Price of firewood	0.021^NS	–0.002^NS	–0.009^NS	0.000^NS
Price of LPG	–0.036^NS	–0.074^NS	–0.008^NS	–0.022^NS
Price of kerosene	–0.314***	–0.018^NS	-0.09**	–0.039^NS
Income	0.000**	0.000^NS	0.000^NS	0.000^NS
Income square	0.000**	0.000^NS	0.000^NS	0.000**
Age	–0.008**	0.00^NS	–0.002^NS	0.000^NS
Age square	0.000***	0.000^NS	0.000^NS	0.000^NS
Sex	0.012^NS	0.026^NS	–0.011^NS	–0.013^NS
Non-institutional education	0.082^NS	–0.018^NS	0.142***	0.046**
Primary	0.072***	0.056***	0.116***	0.035**
High school	0.13***	0.052***	0.144***	0.046***
Higher secondary	0.123***	0.055***	0.158***	0.049***
Collegiate	0.127***	0.062***	0.137***	0.042***
Regular salary earner	–	0.018***	–	0.003^NS
Dwelling units	–	–0.012^NS	–	0.007^NS
Owning land	0.004^NS	0.028^NS	–0.032***	–0.022^NS
Food away from home	–0.003^NS	–0.003^NS	–0.006^NS	0.001^NS
Household size	0.041***	0.007^NS	0.005^NS	0.002^NS
Constant	1.038***	0.972***	0.759***	0.984***

Notes: *** Significant at 1% level, ** Significant at 5% level, NS = Non-significant. Bases: female (sex); illiterate (education); no (regular salary earner); no (own dwelling unit); no (own land); no (food away from home).

Table A2. Results of Estimated Probit Function for Firewood

	Rural		Urban	
	2004–05	**2011–12**	**2004–05**	**2011–12**
Total energy expenditure	–0.044**	0.029NS	–0.182***	–0.039**
Price of electricity	–0.062***	–0.117***	–0.112***	–0.163***
Price of firewood	–0.026***	–0.079***	–0.171***	–0.16***
Price of LPG	0.717NS	–0.567NS	–0.323NS	–0.068NS
Price of kerosene	–0.072**	–0.077NS	–0.28***	–0.188***
Income	0.000***	0.000***	0.000***	0.000***
Income square	0.000***	0.000***	0.000***	0.000**
Age	0.01***	-0.006NS	0.007NS	0.003NS
Age square	0.000***	0.000NS	0.000NS	0.000NS
Sex	–0.004NS	–0.009NS	–0.077**	–0.007**
Non-institutional education	0.035NS	0.039NS	–0.318NS	0.316***
Primary	–0.032***	–0.073***	–0.145***	–0.134***
High school	–0.124***	–0.079***	–0.272***	–0.246***
Higher secondary	–0.189***	–0.162***	–0.404***	–0.305***
Collegiate	–0.3***	–0.234***	–0.333***	–0.319***
Regular salary earner	–	–0.113***	–	–0.074***
Dwelling units	–	–0.037NS	–	0.087**
Owning land	0.128***	0.219***	0.041**	0.036NS
Food away from home	0.008NS	–0.004NS	–0.058***	0.027NS
Household size	0.009***	0.007NS	0.002NS	0.022***
Constant	–1.542NS	3.123**	3.598***	1.466***

Notes: *** Significant at 1% level, ** Significant at 5% level, NS = Non-significant. For bases, see footnote of Table A1.

Table A3. Results of Estimated Probit Function for LPG

	Rural		Urban	
	2004–05	2011–12	2004–05	2011–12
Total energy expenditure	0.334***	0.304***	0.36***	0.266***
Price of electricity	0.075***	0.11**	–0.027^{NS}	0.032^{NS}
Price of firewood	–0.047***	0.041^{NS}	0.025^{NS}	–0.065^{NS}
Price of LPG	–0.564^{NS}	–0.706^{NS}	0.275^{NS}	0.084^{NS}
Price of kerosene	–0.036^{NS}	–0.253***	–0.06^{NS}	–0.392***
Income	0.000**	0.000***	0.000***	0.000^{NS}
Income square	0.000**	0.000***	0.000***	0.000^{NS}
Age	–0.003^{NS}	–0.004^{NS}	0.011^{NS}	0.014***
Age square	0.000^{NS}	0.000^{NS}	0 .000^{NS}	0.000***
Sex	–0.014^{NS}	–0.014^{NS}	0.005^{NS}	–0.047^{NS}
Non-institutional education	0.127^{NS}	0.259^{NS}	0.325**	–0.071^{NS}
Primary	0.052***	0.178***	0.101***	0.087**
High school	0.188***	0.237***	0.317***	0.233***
Higher secondary	0.286***	0.294***	0.463***	0.268***
Collegiate	0.386***	0.368***	0.429***	0.264***
Regular salary earner	–	0.149***	–	0.046***
Dwelling units	–	0.163^{NS}	–	–0.039^{NS}
Owning land	–0.029^{NS}	–0.175^{NS}	0.053***	0.024^{NS}
Food away from home	0.009^{NS}	–0.005^{NS}	–0.013^{NS}	–0.042^{NS}
Household size	0.04***	0.046***	0.03**	0.04***
Constant	0.603^{NS}	1.572^{NS}	–2.74***	–0.268^{NS}

Notes: *** Significant at 1% level, ** Significant at 5% level, NS = Non-significant. For bases, see footnote of Table A1.

Table A4. Results of Estimated Probit Function for Kerosene

	Rural		Urban	
	2004–05	**2011–12**	**2004–05**	**2011–12**
Total energy expenditure	–0.069***	0.034NS	–0.088***	0.084***
Price of electricity	–0.091***	–0.147***	–0.063**	–0.216***
Price of firewood	–0.014NS	–0.038NS	–0.051NS	–0.073NS
Price of LPG	0.001NS	0.605NS	0.002NS	–0.304NS
Price of kerosene	–0.037NS	–0.115***	–0.052NS	–0.27***
Income	0.000***	0.000***	0.000***	0.000***
Income square	0.000**	0.000**	0.000***	0.000***
Age	0.008**	–0.002NS	0.008NS	0.002NS
Age square	0.000**	0.000NS	0.000NS	0.000NS
Sex	0.001NS	0.003NS	–0.079**	–0.005NS
Non-institutional education	–0.053NS	–0.062NS	–0.294NS	0.122NS
Primary	–0.034**	–0.072***	–0.057NS	–0.095**
High school	–0.117***	–0.072**	–0.245***	–0.239***
Higher secondary	–0.163***	–0.116**	–0.411***	–0.306***
Collegiate	–0.367***	–0.185***	–0.42***	–0.386***
Regular salary earner	–	–0.103***	–	–0.001NS
Dwelling units	–	–0.03NS	–	0.01NS
Owning land	0.059**	0.115NS	–0.034NS	–0.016NS
Food away from home	–0.023NS	0.041NS	0.036NS	0.062**
Household size	0.003NS	0.012NS	–0.003NS	0.038***
Constant	1.205NS	–0.902NS	1.481NS	2.181***

Notes: *** Significant at 1% level, ** Significant at 5% level, NS = Non-significant.
For bases, see footnote of Table A1.

Appendix B

Table B1. Results of Estimated QUAIDS Model for Rural Households of Tamil Nadu

	2004–05				2011–12			
	Electricity	**Firewood**	**LPG**	**Kerosene**	**Electricity**	**Firewood**	**LPG**	**Kerosene**
Intercept	0.811***	0.358***	0.335***	–0.504***	0.144*	0.471***	0.793***	–0.408***
Income	–0.244***	0.343***	0.014^{NS}	–0.113***	–0.216***	–0.247***	0.671***	–0.209***
Electricity price	0.048^{NS}	0.056*	–0.053^{NS}	–0.051**	0.03 ^{NS}	–0.068**	0.13^{NS}	–0.092***
Income square	0.042***	–0.077***	0.019**	0.015**	0.158***	0.012^{NS}	–0.285***	0.115***
Firewood price	0.056*	–0.124***	0.093***	–0.025^{NS}	–0.068***	–0.275***	0.494***	–0.151***
LPG price	–0.053^{NS}	0.093***	0.074^{NS}	–0.114***	0.13^{NS}	0.494***	–0.761***	0.137^{NS}
Kerosene price	–0.051**	–0.025^{NS}	–0.114***	0.19***	–0.092***	–0.151***	0.137^{NS}	0.106*
PDF	0.049**	–0.014^{NS}	–0.07**	–0.035*	0.141***	–0.281***	0.148***	0.007^{NS}
e^2	0.121*	0.31***	0.519***	0.95***	–0.862***	0.229**	0.381***	–0.252^{NS}

Note: *** Significant at 1% level, ** Significant at 5% level, * Significant at 10% level, NS = Non-significant.

Table B2. Results of Estimated QUAIDS Model for Urban Households of Tamil Nadu

	2004–05				2011–12			
	Electricity	**Firewood**	**LPG**	**Kerosene**	**Electricity**	**Firewood**	**LPG**	**Kerosene**
Intercept	0.48***	0.041^{NS}	1.13***	–0.651***	0.395***	0.327**	0.632***	–0.354^{NS}
Income	–0.145***	–0.298***	0.75***	–0.307***	–0.27***	–0.223***	0.624***	–0.13***
Electricity price	0.131***	0.001^{NS}	–0.023^{NS}	–0.11***	0.102**	–0.054*	0.045^{NS}	–0.093**
Income square	0.407***	–0.019^{NS}	–0.695***	0.306***	0.3***	0.022^{NS}	–0.394***	0.073***
Firewood price	0.001^{NS}	–0.27***	0.416***	–0.147***	–0.054*	–0.144**	0.314***	–0.115***
LPG price	–0.023^{NS}	0.416***	–0.449***	0.056^{NS}	0.045^{NS}	0.314***	–0.316^{NS}	–0.043^{NS}
Kerosene price	–0.11***	–0.147***	0.056^{NS}	0.202***	–0.093**	–0.115***	–0.043^{NS}	0.25***
PDF	0.16***	–0.177***	0.087***	0.07**	0.145***	–0.163***	0.117***	0.099***
e^2	–0.496***	0.192***	0.647***	0.343**	–1.18***	0.271***	0.413***	–0.496^{NS}

Note: *** Significant at 1% level, ** Significant at 5% level, * Significant at 10% level, NS = Non-significant.

Appendix C
Equations for Expenditure, Price, and Cross Price Elasticities

The expenditure elasticity is estimated as below:

$$\varepsilon_{i,x} = \frac{x}{q_i}\frac{\partial q_i}{\partial x} = \frac{1}{w_i}\left\{\beta_i + \frac{2\lambda_i}{b(p)}\ln x - lxa(p)\right\} + 1 \qquad (3)$$

The uncompensated own-price and cross-price elasticities are estimated as

$$\varepsilon_{i,p} = \frac{1}{w_i}\left\{\gamma_{ii} - \left\langle\left(\alpha_i + \sum_{k=1}^{n}\gamma_{kj}\ln p_k\right)\left[\beta_i + \frac{2\lambda_i}{b(p)}(\ln x - \ln a(p))\right] + \frac{\beta_i}{b(p)}\lambda_i\left[\ln x - \ln a(p)\right]^2\right\rangle\right\} - 1 \qquad (4)$$

$$\varepsilon_{i,p_j} = \frac{1}{w_i}\frac{p_i}{p_j}\left\{\gamma_{ii} - \left\langle\left(\alpha_i + \sum_{k=1}^{n}\gamma_{kj}\ln p_k\right)\left[\beta_i + \frac{2\lambda_i}{b(p)}(\ln x - \ln a(p))\right] + \frac{\beta_i}{b(p)}\lambda_i\left[\ln x - \ln a(p)\right]^2\right\rangle\right\} \qquad (5)$$

The compensated own-price and cross-price elasticities are estimated as

$$\varepsilon^H_{i.p_i} = \varepsilon_{i.p_i} + w_j \varepsilon_{i.x}$$

Appendix D: Derivation of Income Elasticity

In order to estimate income elasticity, Engel curve analysis was conducted and elasticity was estimated. The quadratic form of the Engel function is expressed as

$$\ln fx_h = \alpha_0 + \alpha_1 \ln x_h + \alpha_2 (\ln x)^2 + \beta \ln P + \sum_k \gamma_k HHS_k + \upsilon \quad (6)$$

where, x is expenditure on food and non-food consumer goods and services, is random disturbances assumed with zero mean and constant variance, and P is Laspeyres price index for the aggregate energy source that can be defined by

$$\ln(P) = \sum_i \overline{w_i} \ln(P_i) \quad (7)$$

The quadratic form of Engel function is also useful to validate whether the QUAIDS model can be properly applied to energy demand analysis. Following Deaton and Muellbauer (1980), Equation (6) is estimated via ordinary least squares (OLS).

Blundell, Pashardes, and Weber (1993) indicated that the responsiveness of expenditure on aggregate energy by income change in Equation (6) can be computed as

$$e_y = \alpha_1 + 2\alpha_2 \ln x \quad (8)$$

The income elasticities of demand for aggregate energy source from Equations (3) and (6) are useful to convert the expenditure elasticities from QUAIDS to income elasticities for the fuels. Income elasticity on the basis of QUAIDS model is computed as

$$\eta_i = e_y * \varepsilon_{i,x} \quad (9)$$

Appendix E: Constraints Imposed in the Estimated QUAIDS Model

The following restrictions were econometrically imposed on the parameters of the QUAIDS equation system (2):

$$\sum_{i=1}^{n} \alpha_i = 1; \sum_{i=1,j=1}^{n} \gamma_{ij} = 0; \sum_{i=1}^{n} \beta_j = 0; \sum_{i} \lambda_i = 0 \tag{10}$$

$$\sum_{j} \gamma_{ij} = 0 \tag{11}$$

$$\gamma_{ij} = \gamma_{ji} \tag{12}$$

The equalities in (10) are the adding-up restrictions. They express the property that the sum of the budget shares equals 1 (i.e. $\sum w_{ih} = 1$). The restriction in (11) expresses the prediction that the demand functions are homogenous of degree zero in prices and income. Satisfaction of the restriction in (12) ensures that Slutsky symmetry would hold true.

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