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Household Energy Elasticities in Pakistan: An Application of the LA-AIDS Model on Pooled Household Data

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Abstract

This study aims to estimate the fuel expenditure and price elasticities of household fuels in Pakistan. Burning of wood, animal dung, and crop residues are harmful to health and may cause preventable morbidity and mortality in developing countries. Forests, natural gas and other energy reserves are depleting. It is important to investigate how households' fuel choices are linked to prices, so that governments can consider appropriate steps to enhance the consumption of clean fuels and discourage the use of solid fuels. In this paper we pooled three Pakistan Social and Living Standard Measurement Survey (PSLM) data sets (2007-08, 2010-11 and 2013-14) and applied the Linear Approximate Almost Ideal Demand System (LA-AIDS) model to investigate the price and expenditure elasticities at urban, rural, and national levels. We found that all fuel types except natural gas were price inelastic at the national level and for urban households, implying that changes in prices lead to comparatively lesser changes in quantity demanded of most fuels. In rural areas, natural gas and LPG were found to be more price elastic compared with urban areas. Fuel expenditures elasticities for all fuels were found to be positive and between zero and one. Simple policy simulations based on our results suggest that in order to reduce the indoor air pollution, governments should subsidise clean fuels rather than imposing taxes on solid fuels.

Keywords

household energy
elasticities
LA-AIDS
Pakistan

JEL Classification

O13; P28; Q41

1. Introduction

It is broadly recognized that energy is a lifeline of an economy, and is a key resource for economic growth and development (Sahir and Qureshi 2007). Energy consumption in developing and middle-income economies (Middle East, Southeast Asia, South America, and Africa) will exceed that of developed countries (North America, Australia, New Zealand, Japan, and Western Europe) by 2020 (Pérez-Lombard, Ortiz and Pout 2008). Due to limited resources and increasing demand, especially from developing middle-income countries, the price of energy sources has risen over time (Hadjipaschalis, Poullikkas and Efthimiou 2009). Consequently, the gap between demand and supply of fuels is increasing, especially in developing and middle-income countries. The growing demand for energy and the reliance of countries on limited sources of energy mean that adequate energy provision will be the one of the world's major problems in the next century (Khan and Ahmad 2008).

Around the world, more than two billion people depend upon solid fuels such as charcoal, coal, animal dung, firewood, and crop residues[1] for cooking and heating purposes (Larson and Rosen 2002). When burned, such solid biomass fuels emit a multitude of complex chemicals including carbon monoxide, nitrogen dioxide, formaldehyde, polycyclic aromatic hydrocarbons (PAH), cilia toxic, and others inhalable particulates, damaging the environment and people's health (Cooper 1980 and Torres-Duque, Maldonado, Pérez-Padilla, Ezzati and Viegi 2008). Solid fuels are generally burned in exposed fires or in three-stone stoves, leading to the emission of high levels of these noxious chemicals (Fatmi, Rahman, Kazi, Kadir and Sathiakumar 2010). Mostly as a result of solid fuel use, almost 1.6 million people around the world die prematurely each year due to indoor air pollution, and millions of people are facing serious diseases such as asthma, lung infections, eye infections, sinus problems, tuberculosis (TB), cancer, and cardiovascular diseases (Mishra, 2003; Kim, Jahan, and Kabir 2011, Kim *et al.* 2011, Lakshmi *et al.* 2012, and Sehgal, Rizwan and Krishnan 2014).

The consumption of solid fuels not only affects the population, but also damages the environment. The forests of developing countries are progressively depleting due to wood usage as a household cooking fuel (Arnold, Köhlin and Persson 2006 and Bhatt and Sachan 2004). Forests are necessary for economic, ecological, social, environmental, and health benefits, and provide food, medicines, forest products, and social resources, as well as helping to reduce global warming (Bonan 2008). Despite the adverse effects of biomass fuel on health and the environment, the use of solid fuels for cooking, lighting and heating purposes remains very common in developing and middle-income countries.

Like many other middle-income countries, in Pakistan electricity, firewood, natural gas, crop residues, animal dung, and Liquefied Petroleum Gas (LPG) are the main cooking and

[1] These residues include cotton sticks, bagasse, husks, wheat straw, roots, corn stalks, stubble, leaves and seed pods.

lighting fuels. Usually, electricity is used for lighting whereas other fuels are more commonly used for cooking and heating purposes. In rural areas, the consumption of solid fuels such as firewood, dry animal dung, and crop residues is higher than in urban areas. On the other hand, the consumption of clean energy sources such as natural gas is higher in urban areas than rural areas.

Pakistan has a population of 182 million and ranks as the sixth most populous country in the World (World Bank, 2013). The number of annual deaths attributed to acute respiratory infections (ARI) among children under age five years in Pakistan has been estimated to be 51,760, and a further 18,980 annual deaths due to chronic obstructive pulmonary disease (Colbeck, Nasir and Ali 2010).[2] The total primary energy consumption of Pakistan was 2.54 Quadrillion British Thermal Unit (QBTU) in 2011 (U.S. Energy Information Administration (EIA)). The per capita energy consumption of Pakistan in 2013 was 475 kilograms of oil equivalent per year and Pakistan was ranked at 133 globally.[3]

The six panels of Figure 1 show the overall energy consumption by Pakistani households of natural gas (Panel a), LPG (Panel b), fuelwood (Panel c), bagasse or agricultural waste (Panel d), animal dung[4] (Panel e), and kerosene (Panel f). The consumption of most fuels have an increasing trend, with the exceptions of LPG (which increased to a peak in 2006 then decreased) and kerosene oil (which exhibits a decreasing trend). The reduction in the consumption of LPG can be associated with the increase in the consumption of natural gas. The fluctuation in the in the consumption of the bagasse and crop residues may be because of various factors such as water availability, weather conditions, pests, and relative crops prices.

Pakistan has enough resources to produce sufficient energy to satisfy demand across the country (Ali, Maitla, Murshid and Iqbal 2015). In recent years, the demand for energy has significantly increased, but due to poor policies this increase could not be catered for. Pakistan's energy sector is poorly managed, there is extensive theft of gas and power, and service quality is low. Consequently, power shutdowns (blackouts or brownouts) are very common (Khan and Ahmad 2008), which is not only impeding the development of the country but also badly affecting quality of life (Javed *et al.* 2016).

Despite all of the above, there is a lack of research addressing demand estimation of household energy in Pakistan. The setting of optimal energy prices, levels of subsidies, and levels of taxation on solid and clean fuels has always been a problem for the government. Prices, subsidies, and taxes play a vital role in household energy choices and consumption. In

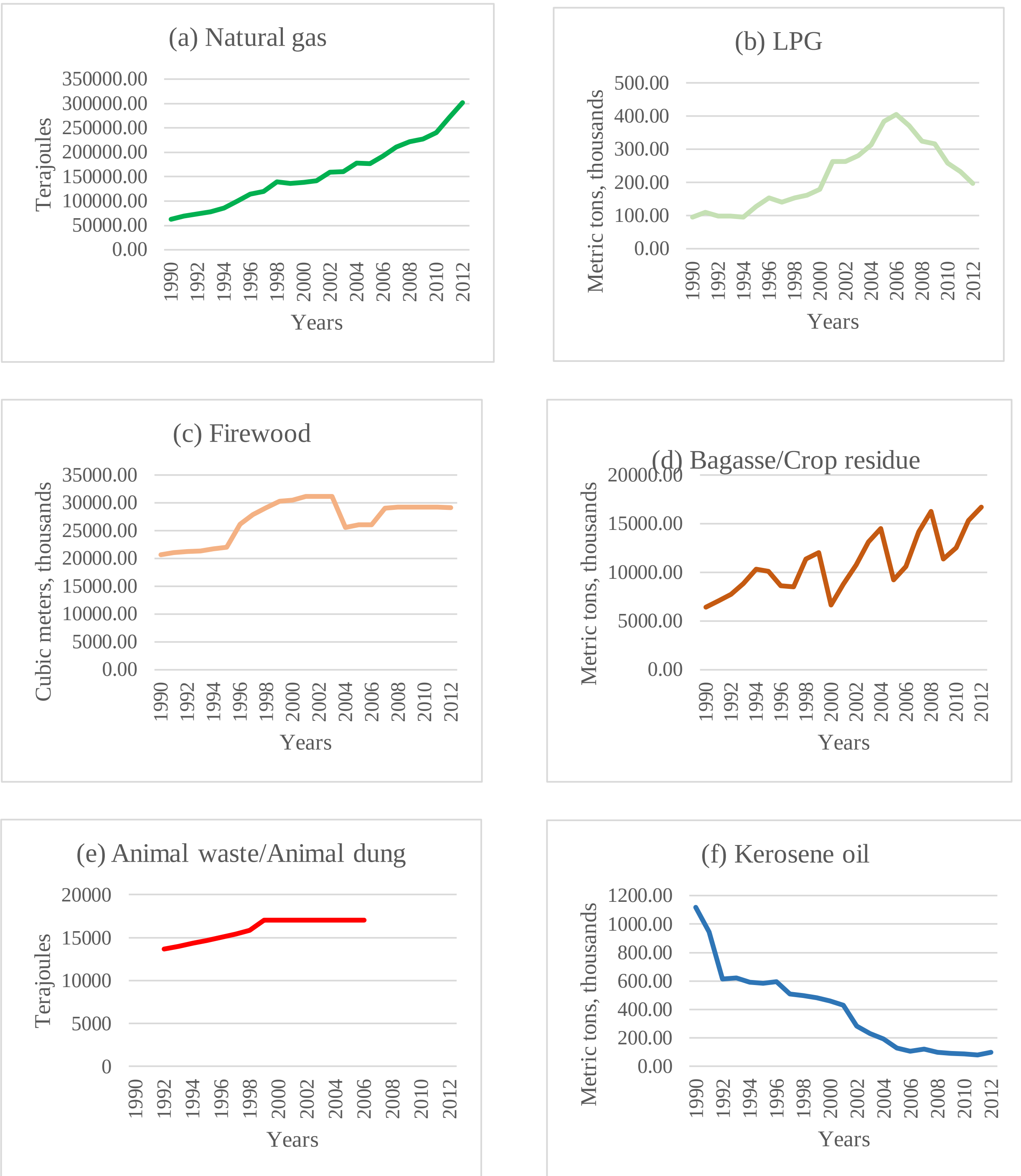
[2] See also: http://www.who.int/indoorair/publications/indoor_air_national_burden_estimate_revised.pdf?ua=1

[3] http://data.worldbank.org/indicator/EG.USE.PCAP.KG.OE

[4] Data are not available for animal dung after 2006.

order to examine the impact of increases or decreases in the prices of energy at the household level, accurate estimates of the price and income elasticities of fuels are imperative. Research studies in Pakistan have mostly estimated the demand elasticities of electricity, while the elasticities of other household fuels have been neglected. We found only two prior studies which had estimated elasticities for other household fuels in Pakistan, those being Iqbal (1983) and Burney and Akhtar (1990).

Figure 1: Fuel Consumption in Pakistan at the Household Level



Source: UN Statistics Division Energy Statistics Database (2015).

The objective of this study is to estimate the uncompensated own price and fuel expenditure elasticities for household cooking and heating fuels in Pakistan. The availability of and preference for fuels are likely to be different for urban and rural households. Therefore, we also estimate the elasticities for rural and urban households separately. We pool three national level micro survey data sets (Pakistan Social and Living Standard Measurement Survey (PSLM) for 2007-08, 2010-11, and 2013-14). The data are comprehensive and cover all the possible cooking and heating fuels used by households. We model energy demand as a multistage budgeting problem, and the allocation of fuel expenditures are analyzed using the Linear Approximate Almost Ideal Demand System (LA-AIDS). The LA-AIDS specification was proposed by Deaton and Muellbauer (1980), and is widely used to estimate price and expenditure elasticities when expenditure share data are available.

The remainder of the paper is organized as follows. Section 2 discusses relevant literature, and in Section 3 we discuss the data and methodology. Section 4 presents the results, Section 5 summarizes and concludes our findings, and Section 6 provides policy implications.

2. Literature Review

There is a limited literature on household cooking and heating energy demand in developing and middle-income countries (Ngui, Mutua, Osiolo and Aligula 2011). Studies such as Filippini and Pachauri (2004) in India, Atakhanova and Howie (2007) in Kazakhstan, Athukorala and Wilson (2010) in Sri Lanka, Shi *et al.* (2012) and Lin, Rizov and Wong (2014) in China, have mainly estimated the demand for electricity. Few studies are available for Pakistan, such as Jamil and Ahmad (2011), and Nasir, Tariq and Arif (2008), but again they are also limited to the one energy source, electricity.

In the Ogun state of Nigeria, Shittu, Idowu, Otunaiya and Ismail (2004) estimated income elasticities for fuels by applying logit models for poor, average, and wealthy households. They found that wood had a negative income elasticity for poor, average, and wealthy households with values of -5.02, -4.94, and -4.31 respectively. Gundimeda and Köhlin (2008) calculated households' price and expenditure elasticities in India by applying the LA-AIDS model, and found positive expenditure elasticities for low, medium, and high income groups in both rural and urban areas. The own price elasticities of electricity, kerosene, fuelwood, and LPG, were almost the same in rural and urban areas. Fuelwood and LPG were almost unitary elastic in all groups.

Arthur, Bond and Willson (2012) investigated the price and income elasticities of domestic energy using the Mozambique National Household Survey on Living Conditions 2002/3. Surprisingly, fuelwood and charcoal were found to be more price inelastic (with values of -0.41 and -0.28 respectively) than electricity (-0.60) and candles (-0.88). On the other hand, candles, kerosene, and electricity were more sensitive to income changes than firewood and charcoal. Similarly, Akpalu, Dasmani and Aglobitse (2011) found that the price elasticity of demand in Ghana was inelastic in the case of charcoal, firewood, and LPG, while kerosene was price elastic. Furthermore, they found that LPG was the most preferred fuel, followed by charcoal, firewood, and kerosene.

In Kenya, Ngui *et al.* (2011) estimated expenditure elasticities and own and cross price elasticities. The researchers found uncompensated price elasticities -0.28, -0.62, -0.67, -0.69, and -0.88 for LPG, fuelwood, charcoal, kerosene and electricity respectively. Surprisingly, kerosene oil was found to be expenditure elastic (1.06), implying that a proportionate increase in expenditure on kerosene oil would be higher than the proportionate increase in the total energy expenditures. They did not estimate elasticities for rural and urban areas separately. For Ethiopia, Guta (2012) calculated only expenditure elasticities and examined the fuel selection of modern and traditional fuels of rural residents. They separated fuels into two groups: (1) traditional (fuelwood, charcoal, leaves, and dung); and (2) modern (biogas and electricity). They found that the expenditure elasticity of the traditional fuel group was inelastic with a value of 0.72 in 2000 and 0.76 in 2004. The expenditure elasticities for the modern fuel group was higher, with values of 1.14 in 2000 and 1.15 in 2004.

There is severe lack of recent literature estimating the price and fuel expenditure elasticities of household cooking fuels in Pakistan. A study conducted by Iqbal (1983) estimated the price and income elasticities of electricity, natural gas, coal, and kerosene. He merged natural gas, LPG, and electricity into one group and merged coal and kerosene into another. The study used time series data (1961-81) and OLS and GLS methods. Both fuel groups were found to be income elastic and price inelastic. LPG and natural gas could feasibly be merged because both are mostly used for cooking purposes. But electricity has an entirely different usage in Pakistan, being mostly used for lighting and to run the electric appliances. Therefore, households' response to changes in the prices of natural gas, LPG, and electricity would be expected to be different. Merging them into a single group may lead to biased estimates.

Burney and Akhtar (1990) used data from the Household Income and Expenditure Survey 1984-85, and applied the Extended Linear Expenditure System to estimate the elasticities. They found that kerosene, natural gas, electricity and other fuels had positive expenditure elasticities, but not firewood. The own price elasticities were also extremely low – firewood had a positive price elasticity with the value of 0.01 for urban areas, whereas all other fuels were noted as highly price inelastic such as kerosene, natural gas, and electricity with values of -0.0018, -0.005, and -0.004 respectively. These elasticities seem implausibly low, and imply that subsidising or taxing the household fuels would not affect the quantity demanded. This may be because this study used cross sectional data and likely had little variation in prices across the sample, particularly given that some fuel prices are set nationally. Moreover, these elasticities are extremely low in comparison to those found in other developing countries, as can be seen in Table 1.

Most studies have used macro data, panel data, or time series data to investigate energy demand, while household-level micro data are rarely used (Sun and Ouyang, 2016). Variation in prices is necessary for the estimation of elasticities. Therefore, some researchers have pooled several cross-sections of data to estimate the elasticities. For instance, in India Bose and Shukla (1999) pooled data from 1985 to 1999 and applied unlagged and lagged models to calculate the price and income elasticities of electricity for commercial, residential, agricultural, large industry, and small and medium industries. Similarly in Spain, Labandeira, Labeaga and Rodríguez (2006) merged three data sets - two cross sectional data sets 1973-74, 1980-81 and one cross sectional time series data set 1985-95 - to observe the variation in prices.

Table 1 summarises the key studies from developing and middle-income countries that are similar to our study. Almost all the studies mentioned in the Table 1 show negative own price elasticities for all of the fuels, except for firewood in the Burney and Akhtar (1990) study in Pakistan (0.01). Some of the studies showed implausibly large elasticities, such as Akpalu *et al.* (2011) in Ghana, who found that the own price elasticity for LPG was -8.90. and Shittu *et al.* (2004), who found the income elasticity for firewood was -4.94.

3. Data and Methods

3.1 Data

Noting the problems with the Burney and Akhtar (1990) study outlined in the previous section, it is important to ensure that there is sufficient price variation in the dataset, particularly given that many fuel prices are set nationally in Pakistan. A single cross-section would not contain sufficient price variation, so instead we pooled several cross-sections of data from the Pakistan Social and Living Standard Measurement Survey (PSLM) for the years 2007-08, 2010-11, and 2013-14. The data consist of a range of socio-economic and demographic variables, including fuel usage.

The data collection frame for the PSLM involves a two-stage stratified sampling design, with every district separated into enumeration blocks containing 200-250 households, and every enumeration block further classified into three categories of income i.e. high, middle, and low. Thus the data is reasonably representative of households in both rural and urban areas in Pakistan. While using this data as a panel for our analysis would be ideal (Labandeira *et al.* 2006), the PSLM data is a repeated cross-section rather than a traditional panel, i.e. it does not necessarily include the same households in each subsequent wave and households cannot be matched across waves of the survey. Therefore we pooled the three cross-sections of data in order to obtain price variation. Initially, in total we have 49,842 households for analysis, of which 15,512 are from 2007-08, 16,341 are from 2010-11, and 17,989 are from 2013-14.

Table 1: Literature Summary

Name	Country	Energy Source(s)	Methodology	Data	Findings	Rural /Urban Classification
Burney and Akhtar (1990)	Pakistan	Electricity, natural gas, firewood, kerosene oil, other fuels	Extended Liner Expenditure System	National Household Income and Expenditure Survey 1984-85 (HIES)	Own price elasticities in urban areas: natural gas -0.08, firewood 0.01, kerosene -0.02 Own price elasticities in rural areas: natural gas missing, firewood -0.09, kerosene -0.09 Expenditures elasticities in urban areas: natural gas 1.03, firewood -0.21 and kerosene 0.37 Expenditures elasticities in rural areas: natural gas missing, firewood 0.45 and kerosene 0.40	Yes
Shittu *et al.* (2004)	Nigeria	Electricity, petrol, diesel, kerosene, firewood, domestic gas and transport in commercial vehicles	Logit model	Primary data from 90 HH, 2002	Average income group level Income elasticities: domestic gas 0.08, wood -4.94, kerosene 0.08	No
Gundimeda and Köhlin (2008)	India	Electricity, LPG, fuelwood and kerosene	Linear Approximate Almost Ideal Demand System (LA-AIDS) model	Cross sectional data collected by National Sample Survey Organisation (NSSO 1999)	Medium expenditure group Own price elasticities in urban areas: LPG -1.01, fuelwood -1.02, kerosene -0.21 Own price elasticities in rural areas: LPG -0.98, fuelwood -1.03, kerosene -0.75 Income elasticities in urban areas: LPG 0.94, fuelwood 1.30, kerosene 0.97 Income elasticities in rural areas: LPG0.96, fuelwood 1.27, kerosene 0.84	Yes
Akpalu *et al.* (2011)	Ghana	LPG, firewood, kerosene, charcoal	Regression analysis	Ghana Living Standards Survey 1998-1999	Own price elasticities: LPG -8.90, firewood -0.87, kerosene -1.29	No

Table 1: Literature Survey *continued*

Name	Country	Energy Source(s)	Methodology	Data	Findings	Rural /Urban Classification
Ngui *et al.* (2011)	Kenya	Electricity, LPG, fuel wood, kerosene, charcoal, MSP, AGO, lubricants	Linear Approximate Almost Ideal Demand System (LA-AIDS) model	Data from Kenya Institute for Public Policy Research and Analysis (KIPPRA) and Energy Regulatory Commission (ERC)	Own price elasticities: LPG -0.28, fuelwood -0.62, kerosene -0.69 Expenditure elasticities: LPG 0.87, fuelwood 0.93, kerosene 1.06	No
Arthur, Bond and Willson (2012)	Mozambique	Electricity, firewood, kerosene, charcoal, candles	Regression analysis developed by Deaton	National Household Survey on Living Conditions 2002/3 Mozambique	Own price elasticities in urban areas: firewood -0.32, kerosene -0.73 Own price elasticities in rural areas: firewood -0.35, kerosene -0.75 Own price elasticities countrywide: firewood -0.41, kerosene -0.79 Income elasticities in urban areas: firewood 0.36, kerosene 0.76 Income elasticities in rural areas: firewood 0.39, kerosene 0.78 Income elasticities countrywide: firewood 0.45, kerosene 0.84	Yes
Sun and Ouyang (2016)	China	Electricity, Natural gas, transport energy	Linear Approximate Almost Ideal Demand System (LA-AIDS) model	China's Residential Energy Consumption Survey 2013	Own price elasticity: natural gas -0.77 Expenditure elasticity: natural gas 0.79	No

Market price data were not available for most fuels, so we divided total expenditures for each fuel by the quantity of that fuel to get the prices for each household. The price of natural gas is set by the Oil and Gas Regulatory Authority (OGRA). Although the wholesale price of LPG is also set by the OGRA, there is small variation in prices because different suppliers offer different consumer prices based on quantity demanded and geographical locations. Given the way that prices are estimated from household data, missing data is a problem (since there is neither expenditure nor quantity data for households that do not consumer a particular fuel type). To deal with the expenditures function and the whole system of equations (see Methods below), prices must exist for all types of energy sources/fuels for all households. Therefore, we used the mean price of that specific fuel type within the same town/cluster as a proxy for missing values. Households (1,921) that did not report expenditures for any fuel type were dropped from the data, leaving 47,921 households for our analysis. Because we have pooled the data across multiple years, we used real prices for the 2007-08 year.

3.2 Methods

To evaluate the own price and fuel expenditure elasticities, we applied the Linear Approximate Almost Ideal Demand System (LA-AIDS) model (Deaton and Muellbauer, 1980). Our dataset does not have market price information, and the LA-AIDS model is widely used for this type of dataset (Arthur, Bond and Willson 2012, Labandeira *et al.* 2006 and Ngui *et al.* 2011). Furthermore, the LA-AIDS model is comparatively easy to evaluate and interpret and fulfils the axioms of choice precisely. It can thus be interpreted in terms of economic models of consumer behaviour when estimated with aggregated or non-aggregated data. It is as flexible as other locally flexible functional forms, and it has the additional benefit of being harmonious with aggregation over consumers. This model is obtained from a detailed cost function and consequently matches a well-defined preference structure, which is also suitable for welfare investigation. In this model, homogeneity and symmetry restrictions depend only on the calculated parameters and are therefore easily tested and/or imposed. The model gives an arbitrary first-order approximation to any demand system. It aggregates perfectly across consumers without invoking parallel linear Engel curves. Finally, it has a functional form that is consistent with known household budget data. Various researchers have applied this model to estimate fuel elasticities (Gundimeda and Köhlin 2008, Ngui *et al.* 2011 and Sun and Ouyang 2016) and many other researchers have applied this model to estimate food demand systems (Agbola 2003, Durham and Eales 2010, Huang and David 1993, Ortega, Holly Wang and Eales 2009 and Taljaard, Alemu and Schalkwyk 2004).

The LA-AIDS models derives a budget share equation from the specification of a Price Independent Generalized Logarithmic (PIGLOG) cost function introduced by (Deaton and Muellbauer, 1980). It is defined as:

$$\ln c(u,p) = (1-u)\, ln\{a(p)\} + u\, ln\{b(p)\} \qquad (1)$$

where u lies between 0 (subsistence) and 1 (bliss) so that *a(p)* and *b(p)* are the costs of subsistence and bliss respectively. The partial derivatives with respect to the prices of the cost function are the quantities demanded, i.e.

$$\ln c(u,p) = \alpha_0 + \sum_i \alpha_i \ln p_i + \frac{1}{2} \sum_i \sum_j \lambda_{ij} \ln p_i \ln p_j + \beta_0 u \prod_i p_i^{\beta_i} \quad (2)$$

where $\ln c(u,p)$ is the cost function for utility *u* at price vector *p*, $\alpha_0, \alpha_i, \lambda_{ij}, \beta_0, and\ \beta_i$ are constants, and *i* and *j* are indexes representing fuel groups, in our case natural gas, LPG, firewood, agricultural waste, animal dung, and kerosene. By applying the shepherd's lemma and substituting in the indirect utility function, we then obtain the expenditure share of the i^{th} group of fuels from Equation (2), $\frac{\partial c(u,p)}{\partial p_i} = q_i$ (Shephard 1970 and Diewert 1971). By multiplying both sides by $p_i/c(u,p)$, we obtain:

$$\partial \ln \frac{c(u,p)}{lnp_i} = \frac{p_i q_i}{c(u,p)} = w_i \quad (3)$$

where $w_i = \frac{p_i q_i}{x}$ is the budget share of good *i*. We can then obtain the budget share as a function of utility and price. For maximizing the utility total expenditures, *x* is equal to *c(u,p)*, and we can obtain *u* as a function of *p* and *x*. Then we can also obtain the budget share as a function of *p* and *x*. The LA-AIDS demand equation in budget share form is:

$$w_i = \alpha_i + \sum_i \gamma_{ij} \ln(p_j) + \beta_i ln\left(\frac{x}{P^*}\right) \quad (4)$$

The model uses the budget shares of each commodity group as dependent variables, and the natural logarithm of prices and real expenditure/income as independent variables. This model satisfies the desirable properties of the demand system, and p_j is the price of good *j*, *x* is total expenditure given by $x = \sum p_i q_i$, where q_i is the quantity demanded and p_i is the price for i^{th} group of fuels of the particular household. P^* is a Stone price index and is defined as follows:

$$\ln P^* = \alpha_0 + \sum_{I=1}^{n} \alpha_i \ln p_i + \frac{1}{2} \sum_i^n \sum_j^n \gamma_{ij} \ln p_i \ln p_j \quad (5)$$

$$\gamma_{ij} = \frac{1}{2}(\gamma_{ij} * + \gamma_{ji} *) \quad (6)$$

$$\ln P^* = \sum w_j \ln p_j \quad (7)$$

where $ai, \gamma ij, and\ \beta_i$ are parameters to be estimated. To comply with the theoretical properties of consumer theory, the following restrictions on the demand function are imposed during estimation:

$$\sum_i^n a_i^* = 1, \quad \sum_i^n \gamma_{ij} = 0, \quad \sum_i^n B_i = 0 \qquad \forall all\ i \tag{8}$$

$$\sum_i^n \gamma_{ij} = 0, \quad \forall\ j \tag{9}$$

$$\gamma_{ij} = \gamma_{ji} \tag{10}$$

Equation (8) is an adding up constraint, it ensures that the budget shares sum to unity. Equation (9) is a homogeneity restriction, it is based on the assumption that a proportional change in all prices and expenditures does not affect the quantities purchased. Equation (10) is a symmetry restriction and it imposes consistency of consumer choice. Imposing the property of additivity of the expenditure function makes the variance and covariance matrix singular, and one of the equations needs to be omitted to estimate the LA-AIDS model. The uncompensated (Marshallian) own and cross price elasticity for good (i) with respect to good (j) is estimated as:

$$e_{ij} = -\delta_{ij} + \frac{\gamma_{ij-\beta_i}}{w_i} \tag{11}$$

where δ_{ij} is the Kronecker delta and equals one for own-price and zero for cross-price elasticities. The uncompensated elasticity of demand represents changes in the quantity demanded as a result of changes in prices, capturing both substitution and income effects. Finally, the fuel expenditure elasticities are estimated by:

$$E_i = 1 + \frac{\beta_i}{w_i} \tag{12}$$

The seemingly unrelated regression estimation (SURE) method of (Zellner 1962) is employed to estimate the system of equations (1 to 12). The SURE Demand system allows restrictions inferred by economic theory to be imposed not only within an equation (such as the homogeneity restriction from Equation (9)), but also across different equations (such as the symmetry and adding up constraints in Equations (10) and (8) respectively). This improves efficiency, by estimating the model as a demand system. Moreover, a system of equations approach is more efficient than single equation models if the disturbance terms in different equations are correlated (Asatryan, 2004).

4. Results and Discussion

Table 2 shows the mean consumption of each fuel at the household level. The mean consumption of firewood, agricultural waste, and animal dung in rural areas is higher than in urban areas, due to greater access and availability of these fuels. The consumption of piped natural gas is higher in urban areas due to the higher number of gas connections, while the consumption of LPG is higher in rural areas because there are fewer natural gas connections.

Table 2: Monthly Fuel Consumption

Fuels	Urban		Rural		National	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Natural gas (MMBTU)	0.90	1.72	0.43	1.41	0.66	1.59
LPG (Kg)	0.42	2.02	0.74	2.71	0.58	2.40
Firewood (Kg)	49.68	84.60	73.60	114.43	61.80	101.52
Agricultural waste (Kg)	22.29	61.15	28.91	74.50	25.64	68.32
Animal dung (dry) (Kg)	21.48	70.98	23.77	60.29	22.64	65.79
Kerosene (L)	0.13	0.67	0.36	0.94	0.25	0.82

Similarly, Table 3 shows the average monthly expenditures on household fuels. Interestingly, while the consumption of fuelwood, crop residues, and animal dung is higher in rural areas than urban areas as shown in Table 2, the mean expenditures on these fuels are lower in rural areas. There could be two reasons of this. First, it is easier to access these fuels in rural areas and second, sometimes landlords or farmers do not charge households in rural areas for crop residues or animal dung.

Table 3: Monthly Fuel's Expenditures PKR

Fuels	Urban		Rural		National	
	Mean (PKR)	Std. Dev.	Mean (PKR)	Std. Dev.	Mean (PKR)	Std. Dev.
Natural gas (MMBTU)	183.72	366.65	117.60	392.69	150.23	381.50
LPG (Kg)	47.84	236.90	76.69	301.16	62.45	271.74
Firewood (Kg)	364.39	705.03	339.19	491.57	351.62	606.51
Agricultural waste (Kg)	82.85	231.43	70.93	188.57	76.81	210.90
Animal dung (dry) (Kg)	67.44	203.10	54.11	140.27	60.69	174.26
Kerosene (L)	12.39	69.71	21.31	59.20	17.17	64.73

Notes

Inflation adjusted 2007, PKR 61=$ 1, Pakistani rupee (PKR).

Table 4 shows the uncompensated own price elasticities obtained from the LA-AIDS model for different cooking fuel types at the national level, and separately for urban and rural households. Natural gas (piped gas) was the only fuel type found to be price elastic, and was so at the national level and in both urban and rural areas, implying that natural gas is relatively more price sensitive than all other fuels. The coefficient for piped gas in urban areas is similar in sign to Burney and Akhtar (1990), but in our analysis it is far more price elastic than their estimate of -0.087. Recall that Burney and Akhtar (1990) used a single cross-section of data, and their low results may be due to a lack of variation in observed prices.

Interestingly, natural gas is relatively more price elastic in rural areas than urban areas. Liquefied petroleum gas (LPG) is price inelastic at the national level and in both urban and rural areas, but is relatively less price inelastic in urban areas than rural areas. Natural gas and LPG are both relatively more price sensitive in rural areas than urban areas, and this may be due to the availability of cheap alternative fuels like crop residues and animal dung. LPG was also noted as price inelastic in many other studies, such as Athukorala and Wilson (2010), Guta (2012) and Ngui *et al.* (2011).

Table 4: Own Price Elasticities

	National Level		**Urban**		**Rural**		**z-test**
Energy sources	coef.	std.err	coef.	std.err	coef.	std.err	p-value
Natural gas	-1.448***	-0.032	-1.390***	0.047	-1.613***	0.047	<0.001
LPG	-0.738***	0.021	-0.484***	0.031	-0.866***	0.033	<0.001
Firewood	-0.711***	0.018	-0.133***	0.047	-0.836***	0.015	<0.001
Crop residues	-0.733***	0.007	-0.628***	0.014	-0.761***	0.008	<0.001
Animal dung (dry)	-0.908***	0.005	-0.960***	0.009	-0.881***	0.007	<0.001
Kerosene oil	-0.595***	0.018	-0.647***	0.025	-0.508***	0.028	<0.001

Notes

*** p<0.01, ** p<0.05, * p<0.1, z-test results are based on the procedure in Clogg, Petkova and Haritou (1995).

Firewood was found to be price inelastic at the national level and in both urban and rural areas, and in urban areas it was relatively less price inelastic than in rural areas. Our results contradict those of Burney and Akhtar (1990), as they found a positive price elasticity of firewood in urban areas (0.014), but as noted earlier those results are suspect. Many researchers such as Arnold *et al.* (2006), Ngui *et al.* (2011), Akpalu *et al.* (2011) and Arthur *et al.* (2012) have found that firewood is price inelastic. Our results show that crop residues is also price inelastic at the national level and in both urban and rural areas, and slightly more price elastic in rural areas than in urban areas.

We find that dry animal dung is price inelastic in both rural and urban areas, and slightly more inelastic in rural areas than in urban areas. Kerosene oil is the most price inelastic source among our selected household fuels at the national level, and in rural areas. However, in urban areas the price elasticity is higher than in rural areas, albeit still price inelastic, and slightly more price elastic than crop residues. Overall, our finding that kerosene oil is price inelastic is similar to the findings of Ngui *et al.* (2011), Akpalu *et al.* (2011) and Arthur *et al.* (2012).

Table 5 presents the fuel expenditure elasticities of the households obtained from the LA-AIDS model at the national level, and separately for urban and rural areas. All fuel types have positive coefficients, greater than zero but less than one. This implies that as households' total fuel expenditures increase, the quantity demanded of each fuel would also rise but proportionately less than total fuel expenditures. These results are unremarkable since, as the quantity of fuels consumed rise, expenditure on fuels (as a group) can also be expected to rise.

They provide, however, confidence that the LA-AIDS model is producing sensible estimates. In most cases, the differences between rural and urban areas, in terms of fuel expenditure elasticity, are small but statistically significant. The largest differences are observed for firewood and LPG, where the fuel expenditure elasticities are greater in rural areas than in urban areas. For firewood, the findings are similar to Arthur *et al.* (2012), but in contrast to Burney and Akhtar (1990) as they found a negative expenditure elasticity for firewood for urban households (-0.21).

Table 5: Expenditures Elasticities

	National Level		**Urban**		**Rural**		**z-test**
Energy sources	coef.	std.err	coef.	std.err	coef.	std.err	p-value
Natural gas	0.888***	0.006	0.814***	0.014	0.934***	0.006	<0.001
LPG	0.838***	0.006	0.728***	0.012	0.880***	0.006	<0.001
Firewood	0.840***	0.012	0.559***	0.025	0.905***	0.011	<0.001
Agricultural waste	0.883***	0.007	0.841***	0.013	0.882***	0.009	<0.001
Animal dung (dry)	0.914***	0.007	0.981***	0.013	0.900***	0.008	<0.001
Kerosene oil	0.906***	0.006	0.837***	0.011	0.938***	0.008	<0.001

Notes

*** p<0.01, ** p<0.05, * p<0.1, z-test results are based on the procedure in Clogg *et al.* (1995) .

The estimated fuel expenditure elasticity for dry animal dung is a bit higher in urban areas than in rural areas. Many rural inhabitants have cattle and therefore they do not need to spend more on dung as their energy expenditures rise, and this could be the cause of the lower fuel expenditure elasticity in rural areas. The fuel expenditure elasticity of kerosene oil in rural areas is a bit higher than in urban areas. Many urban households have piped gas connections, therefore they do not spend more on kerosene oil as their energy expenditures rise and this could be a cause of the lower fuel expenditures elasticity in urban areas. Many other studies in developing countries also found fuel expenditures elasticity of less than one for kerosene oil such as Burney and Akhtar (1990), Arnold *et al.* (2006) Gundimeda and Köhlin (2008) and Arthur *et al.* (2012,) but in Kenya Ngui *et al.* (2011) found fuel expenditure elasticity of kerosene oil to be slightly greater than one (1.06).

5. Simple Policy Simulation

The ill health effects associated with burning of solid fuels and kerosene are stated in many research studies (e.g. see Fatmi *et al.* 2010). The cutting of wood for cooking purposes also decreases forest resources and consequently, the depleting of the forest leads to the numerous environmental problems (Arnold, Köhlin, and Persson, 2006; Bhatt and Sachan, 2004; Bonan, 2008). Therefore, it is important for governments to consider policies that encourage the use of cleaner fuels and disincentivise the use of solid fuels. Like many other developing and middle-income countries, the Government of Pakistan also wants to reduce the use of solid fuel at household level to control the associated ill effects on health and environment.

For this purpose, we estimated what would happen if government subsidises clean fuels (Natural gas and LPG) or imposes taxes on dirty fuels (Firewood, Animal dung, Agricultural waste, and Kerosene). These policy simulations are based on the estimated cross price elasticities from the LA_AIDS model. Specifically, we consider the impact of a 10 percent subsidy on each clean fuel (natural gas and LPG), and the impact of a 10 percent tax on each solid fuel (firewood, crop residues, dry animal dung) and kerosene. Each simulation (subsidy or tax) is evaluated separately, and for simplicity we only consider the first-order impacts of the change in prices on consumption of each of the other fuels. The purpose of the simulation is to identify in a general sense whether subsidies of clean fuels, or taxes of solid fuels or kerosene, would be more effective in inducing households in Pakistan to substitute their fuel use towards clean fuels, and which of the two subsidy options (natural gas or LPG) would be more cost-effective. The results of these simulations are shown in Table 6 with detailed tables of cross-price elasticities given in the Appendix.

Table 6: Effects of Price Changes on Quantity Demand

Change in Price of Energy Source	Area	Q.NG	Q.LPG	Q.FW	Q.AW	Q.AD	Q.KO
Natural Gas 10% ↓	Urban	13.90% ↑	6.45% ↓	3.32% ↓	1.09% ↓	1.21% ↓	2.99% ↓
	Rural	16.13% ↑	6.09% ↓	0.70% ↓	0.01% ↓	0.28% ↓	2.44% ↓
LPG 10% ↓	Urban	4.58% ↓	4.84% ↑	5.14% ↓	0.94% ↓	1.72% ↓	1.16% ↑
	Rural	4.49% ↓	8.66% ↑	1.35% ↓	0.47% ↓	0.52% ↓	1.95% ↑
Firewood 10% ↑	Urban	3.75% ↑	6.46% ↑	1.33% ↓	3.45% ↑	2.93% ↑	1.29% ↑
	Rural	0.76% ↑	1.10% ↑	8.36% ↓	0.50% ↑	0.67% ↑	0.22% ↑
Crop Residues 10% ↑	Urban	0.99% ↑	0.12% ↑	3.09% ↑	6.28% ↓	1.34% ↑	0.33% ↑
	Rural	0.49% ↑	0.92% ↑	1.23% ↑	7.61% ↓	0.87% ↑	0.19% ↑
Animal Dung 10% ↑	Urban	0.10% ↑	0.00% ↑	0.18% ↑	0.44% ↑	9.60% ↓	0.04% ↑
	Rural	0.71% ↑	0.83% ↑	1.41% ↑	0.80% ↑	8.81% ↓	0.19% ↑
Kerosene Oil 10% ↑	Urban	8.69% ↑	7.42% ↓	3.05% ↑	0.89% ↑	1.08% ↑	6.47% ↓
	Rural	8.54% ↑	11.26% ↓	0.66% ↑	0.13% ↑	0.22% ↑	5.08% ↓

If the government were to subsidise natural gas such that consumer prices fell by 10 percent, the consumption of natural gas would increase by 13.90 percent in urban areas and by 16.13 percent in rural areas. Although the increment in the consumption of natural gas in urban areas would be a bit lower than rural areas, the reduction in solid fuel use would be higher than in rural areas, as shown in the table. However, in the case of subsidising LPG (again such that consumer prices fell by 10 percent), consumption of LPG would increase by a greater proportion in rural areas than in urban areas, while as is the case for natural gas solid fuel reduction would be greater in urban areas.

Government has only limited influence in setting the prices of solid fuels, because solid fuels often do not have complete markets, although firewood is traded relatively more frequently that agricultural waste or animal dung. Therefore, taxing solid fuels can be a very challenging task. In any case if the government imposes a tax on firewood and consequently consumers face a 10 percent increase in the price of firewood, it would reduce the quantity demanded of firewood by 1.33 percent in urban areas and 8.36 percent in rural areas. Interestingly, taxing firewood would increase the quantity demanded of LPG comparatively more than natural gas, especially in urban areas.

Although there is no proper market for other solid fuels (crop residues and animal dung) we show the effect of a tax that would increase their price by 10% for comparative purposes. In both cases, the effect of the tax on the consumption of clean fuels (LPG and natural gas) is much smaller than either a tax on firewood, or subsidies on natural gas or LPG. Finally, our estimates show that taxing kerosene oil by 10 percent would increase the use of natural gas by more than 8 percent in rural and urban areas, and reduce kerosene consumption by 6.47 percent in urban areas and 5.08 percent in rural areas.

According to our estimates, if the Pakistan government provides a 10 percent subsidy on natural gas to households it will cost around 22 PKR per unit, and in total it would cost annually 46,894,082 PKR (46.8 Million USD[5]). Total consumption of firewood in urban area is 858,357 tonnes[6] annually and 9,541,285 tonnes annually in rural areas. By subsidising natural gas the consumption of firewood will be reduced by 3.32 percent (28,497.4 tons) in urban areas and by 0.70 percent (66,788.9 tons) in rural areas. Similarly, total agricultural waste consumption in urban areas is 159,549.8 tons per annum and in rural area it is 1,270,154.4 tons per annum. After subsidizing natural gas the agricultural wastes will be decreased by 0.01 percent (127 tons) in rural areas and 1.09 percent (1739 tons) in urban areas annually. Annual animal dung consumption in urban areas is 111,337.6 tonnes and in rural areas it is 1,526,291.6 tons. After subsidizing natural gas, the animal dung consumption will be decreased by 1.21 percent (1,347 tons) and 0.28 percent (4,273 tons) in urban and rural areas respectively. Overall the consumption of firewood would be decreased by 95,286.3 tons, crop residue by 1,866 tons, and animal dung by 5,620 tons, at a total cost of nearly 47 billion PKR.

If the government instead provided a 10 percent subsidy on LPG to households it will cost around 11 PKR at per unit and in total it would cost 26,38,350,000 PKR (263.83 million USD) annually. This would reduce firewood use by 5.14 percent (44,119.5 tons) in urban areas and by 1.35 percent (128,807.3 tons) in rural areas annually. Similarly, crop residue would be decreased by 0.94 percent (1,499.7 tons) in urban areas and 0.47 percent (5,969.7 tons) in rural areas annually. In the same way, the consumption of animal dung would be

[5] 2014 exchange rate, 100 PKR = 1 USD
[6] tonne = 1000 kg

decreased by 1.72 percent (1,915 tons) in urban areas and 0.52 percent (7,936 tons) in rural areas annually. Overall, the consumption of firewood will be decreased by 172,926.8 tons, crop residue by 7469.4 tons and animal dung by 9851 tons, at a total cost of under 27 billion PKR. Comparing the two subsidies, it is clear that subsidising LPG dominates a subsidy of natural gas, producing a greater reduction in solid fuel use and at a lower total cost.

6. Conclusions

This study applied the Linear Approximate Almost Ideal Demand System (LA-AIDS) model to estimate price and fuel expenditure elasticities in Pakistan. The complete energy demand model was estimated using Seemingly Unrelated Regression with adding up, homogeneity and symmetry restrictions. The own price elasticities suggest that all fuel types are price inelastic except for piped natural gas. For most fuel types (except animal dung and kerosene oil) demand was found to be more price elastic in rural areas than in urban areas, probably due to the ready availability of cheap or near-free substitutes (animal dung or crop residues) in rural areas. The fuel expenditure elasticities were less than one and the differences between rural and urban areas in fuel expenditure elasticities were not large, but were statistically significant.

We conducted simple policy simulations to suggest what would happen if government imposes taxes on solid fuels or provides subsidies on clean fuels. We found that subsidizing LPG dominates a subsidy of natural gas, producing a greater reduction in solid fuel use at a lower total cost to the government. If the government wants to subsidise only one clean fuel, they should subsidise LPG instead of natural gas.

There are still a number of improvements that could be made to this approach. Cross sectional sample survey data makes it difficult to calculate price elasticities, primarily due to the lack of variation in prices and the potential for unobserved variables such as idiosyncratic differences in fuel preferences between households to create bias in the results. We tried to avoid the former problem by pooling several cross-sectional data sets, but it would be better if panel data were available since that would also deal with unobserved time-invariant differences across households. We could not follow a panel approach with our data, because the identity of households was not tracked between survey waves. While we investigated price and fuel expenditure elasticities, and the potential impacts of changes in taxes and subsidies, there are a number of other factors that affect household fuel selection in Pakistan. Future research should also investigate the non-price determinants of household fuel choices. Furthermore, while we have conducted a simple policy simulation of the effect of changes in taxes or subsidies, more detailed analysis could be conducted in the future to better evaluate the costs and benefits of changes in fuel use.

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Appendix

Table 7: Own and Cross-Price Elasticities at National Level

Energy sources	Natural gas	LPG	Firewood	Agri. waste	Animal dung	Kerosene oil
Natural gas	**-1.448 (0.032)**	0.573 (0.031)	0.157 (0.009)	0.027 (0.005)	0.068 (0.004)	0.248 (0.01)
LPG	0.402 (0.019)	**-0.738 (0.021)**	0.246 (0.009)	0.059 (0.005)	0.091 (0.004)	-0.155 (0.006)
Firewood	0.131 (0.01)	0.218 (0.017)	**-0.711 (0.018)**	0.113 (0.009)	0.1 (0.008)	0.042 (0.003)
Agri. waste	0.038 (0.008)	0.05 (0.012)	0.178 (0.011)	**-0.733 (0.007)**	0.098 (0.005)	0.021 (0.003)
Animal dung	0.068 (0.007)	0.088 (0.01)	0.123 (0.011)	0.085 (0.005)	**-0.908 (0.005)**	0.022 (0.002)
Kerosene oil	0.785 (0.032)	-0.901 (0.032)	0.139 (0.01)	0.038 (0.006)	0.057 (0.005)	**-0.595 (0.018)**

Notes

Own price elasticities are along the diagonal and those off the diagonal are cross-price elasticities.
Standard errors are given in the parenthesis.

Table 8: Own and Cross-Price Elasticities in Urban Area

Energy sources	Natural gas	LPG	Firewood	Agri. waste	Animal dung	Kerosene oil
Natural gas	**-1.39 (0.047)**	0.645 (0.046)	0.332 (0.027)	0.109 (0.014)	0.121 (0.01)	0.299 (0.014)
LPG	0.458 (0.026)	**-0.484 (0.031)**	0.514 (0.023)	0.094 (0.01)	0.172 (0.008)	-0.116 (0.008)
Firewood	0.375 (0.022)	0.646 (0.036)	**-0.133 (0.047)**	0.345 (0.019)	0.293 (0.017)	0.129 (0.007)
Agri. waste	0.099 (0.015)	0.012 (0.022)	0.309 (0.025)	**-0.628 (0.014)**	0.134 (0.009)	0.033 (0.005)
Animal dung	0.010 (0.012)	0.000 (0.019)	0.018 (0.024)	0.044 (0.01)	**-0.96 (0.009)**	0.004 (0.004)
Kerosene oil	0.869 (0.043)	-0.742 (0.042)	0.305 (0.022)	0.089 (0.012)	0.108 (0.008)	**-0.647 (0.025)**

Notes

Own price elasticities are along the diagonal and those off the diagonal are cross-price elasticities.
Standard errors are given in the parenthesis.

Table 9: Own and Cross-Price Elasticities in Rural Areas

Energy sources	Natural gas	LPG	Firewood	Agri. waste	Animal dung	Kerosene oil
Natural gas	**-1.613 (0.047)**	0.609 (0.046)	0.07 (0.007)	0.001 (0.005)	0.028 (0.005)	0.244 (0.014)
LPG	0.449 (0.03)	**-0.866 (0.033)**	0.135 (0.008)	0.047 (0.005)	0.052 (0.005)	-0.195 (0.009)
Firewood	0.076 (0.011)	0.11 (0.016)	**-0.836 (0.015)**	0.05 (0.008)	0.067 (0.008)	0.022 (0.003)
Agri. waste	0.049 (0.01)	0.092 (0.014)	0.123 (0.012)	**-0.761 (0.008)**	0.087 (0.007)	0.019 (0.003)
Animal dung	0.071 (0.009)	0.083 (0.013)	0.141 (0.011)	0.08 (0.007)	**-0.881 (0.007)**	0.019 (0.003)
Kerosene oil	0.854 (0.049)	-1.126 (0.052)	0.066 (0.011)	0.013 (0.007)	0.022 (0.007)	**-0.508 (0.028)**

Notes

Own price elasticities are along the diagonal and those off the diagonal are cross-price elasticities.
Standard errors are given in the parenthesis.