Environment and Development Economics 10: 337–361 © 2005 Cambridge University Press
doi:10.1017/S1355770X04001858 Printed in the United Kingdom

Factors determining household fuel choice in Guatemala

RASMUS HELTBERG
The World Bank, 1818 H Street, NW, Washington, DC 20433, USA. E-mail: rheltberg@worldbank.org

ABSTRACT. This paper discusses the factors guiding household choices of cooking fuels. This is crucial for policies to combat indoor air pollution. Household income is an important, but not the only, factor. Opportunity costs of firewood also play an essential role. Empirical results are based on the 2000 Guatemalan LSMS survey, which includes a detailed section on energy use. Patterns of fuel use, energy spending, Engel curves, multiple fuels, the extent of fuel switching, and the determinants of fuel choice are analyzed.

It is common in Guatemala to use multiple fuels for cooking – 48 and 27 per cent of urban and rural households do so. Modern fuels are often used alongside traditional solid fuels; modern fuels thus fail to displace solid fuels in many cases, particular in rural areas and the urban bottom half. This is paradoxical since a significant share of firewood users buy wood from the market, incurring costs that are substantial, also in comparison with the costs of modern fuels.

1. Energy, health, and poverty

Around 2.4 billion people in developing countries rely primarily on traditional biomass fuels for their cooking and heating needs (IEA, 2002). Biomass fuels used in inefficient and traditional ways have severe implications for health, productivity, and the environment.

Indoor air pollution from solid fuel use is a major cause of death and disease – the World Health Organization ranks indoor air pollution from solid fuels the world's eighth largest health risk, causing 2.7 per cent of global losses of healthy life (WHO, 2002).[1] Indoor air pollution is caused by households burning solid fuels such as wood, charcoal, coal, cow dung,

Comments from Masami Kojima, Robert Bacon, seminar participants at the World Bank, and two anonymous referees of this journal are gratefully acknowledged. The author is solely responsible for errors and judgments. The views expressed in this article are entirely those of the author and should not be attributed in any manner to the World Bank, to its affiliated organizations, or to the members of its Board of Directors or the countries they represent.

[1] Not all the epidemiological studies have controlled adequately for confounding factors such as socio-economic variables that jointly affect fuel type and health status, but evidence from Guatemala suggests the link between fuel type and respiratory health does hold once confounding factors are controlled for (Bruce *et al.*, 1998; Torres, 2002).

and crop residues in traditional stoves with inadequate ventilation. Solid fuels emit particulates and harmful gasses when burnt, causing elevated levels of indoor exposure that can reach 10–20 times above safe limits. Women, children, and the elderly are particularly exposed. The result is acute respiratory infections, chronic obstructive pulmonary disease (such as bronchitis), eye problems, and cancer of the lungs. Burns from open fires pose another significant health hazard.

Solid fuels burnt by households also contribute to *outdoor air pollution* when smoke is vented through chimneys and windows, contributing to high concentrations of particulates. This is especially a problem in densely populated urban areas, and in cities relying heavily on coal.

Energy affects human *productivity* in many ways: when long hours are spent collecting biomass fuels; because of ill health and sore eyes induced by smoke; when animal dung is diverted to be used as a fuel instead of being used as a fertilizer to replenish soil nutrients. Electricity is also important for productivity: households that lack electricity frequently constrain activities after dark. This causes loss of productive time available and hinders school performance since alternative sources of light are of low quality; voltage fluctuations damage equipment; and the need for expensive investment in backup power sources constrains business growth.

The link from fuelwood collection to forest degradation and soil erosion is more complex than normally acknowledged. Firewood collection was previously thought to be massively unsustainable and an impending 'other energy crisis' of massive wood shortages was predicted (Eckholm, 1975); this is now known not to be true at the global level. Most deforestation is caused by clearing for agriculture and logging, not by wood collection. In the Sahel and other drylands, for example, limited tree cover was previously believed to be a sign of deforestation, but new research has ascertained that many such landscapes are at their climax vegetation. Scarce rainfall rather than anthropoid causes generates the prevailing vegetation patterns (ESMAP, 2001). The impact of firewood collection is highly localized. Much wood is not collected from forested land. Firewood collection causes forest degradation only in certain places, particularly in areas of high population density, around cities, on fragile and sloping lands, and where common property resources are not managed well (Heltberg, 2001).

On the positive side, collection and marketing of biomass fuels for sale is a source of local employment available also for the poorest of the poor who can rely on open access resources for its collection.

Improving access to and use of clean and efficient energy is therefore an important part of the struggle against poverty and underdevelopment (Smith, 2002). Clean, safe and efficient energy is a merit good that greatly enhances consumer welfare. Development agencies pursue several different strategies in this field. Among these, the most important are interfuel substitution and improved stoves.

The first option, promotion of interfuel substitution, is to try inducing biomass-consuming households to switch into cleaner alternatives such as liquefied petroleum gas (LPG) or kerosene. This is often conceptualized as speeding up a fuel 'switching' or 'transition' process expected to take place anyway. Many countries have used some version of this argument to motivate subsidies for LPG or kerosene. Such subsidy programs are often ill targeted and can carry sizeable fiscal costs. Subsidies on recurrent consumption of energy therefore need to be carefully assessed. An interesting idea is to redirect subsidies on recurrent use of energy (cooking fuels or electricity) to cover uptake costs, possibly targeted at the poor (ESMAP, 2000). This is because energy uptake or connection costs are often quite substantial. For LPG households, subsidies could pay for fuels, be invested in a stove, and purchase or give a deposit for the cylinder. Some households even invest in two cylinders to ensure continued use of LPG during cylinder refill. Such cash uptake costs are often thought to constrain LPG penetration among low-income and subsistence households.

The second option is to promote improved and more efficient biomass stoves. If well-designed, improved stoves emit significantly less smoke, often by venting smoke through a chimney. China, India, Guatemala and many other developing countries have had large-scale improved stove programs with varying success. Most of the programs have made improved stoves available at subsidized rates, hindering their commercialization. These programs have encountered problems such as poor durability of the stoves, inappropriate stove designs that fail to take users, needs into account, and lack of technical support once installed in the field. Although more evaluation of their impact on exposure reduction is required, some 'improved' stoves emit significant amounts of particulate matter resulting in hazardous exposure levels, low only by comparison to the open burning of wood (and occasionally higher). Moreover, by venting smoke outdoors, improved stoves are not a solution to outdoor air pollution (Smith, 1999).

Both options – fuel substitution and improved stoves – face challenges relating to adoption and use. It has proven far from easy to get households to adopt them. And, once adopted, they are not necessarily used to their full extent: improved stoves are sometimes used only for part of the cooking, and many households rely on multiple fuels, both modern and traditional. And, once adopted, stoves and fuels are sometimes later abandoned. Issues of affordability affect uptake of both improved stoves and modern fuels. Uptake is particularly challenging in rural areas with easy access to free biomass, where people see little need for switching into costlier alternatives or to invest in a wood-saving stove. The urban situation is different, though. Many residents in cities rely on purchased wood that is sufficiently costly as to provide a financial incentive for stove adoption or fuel switching. Apartment residents may not be allowed to cook with wood because of smoke considerations. Difficulties of financing the stove investment and the start-up costs of petroleum fuels are often mentioned as barriers for uptake. Cooking habits and taste preferences in those accustomed to traditional wood-stoves may also play a role. For successful adoption and continued use, it is necessary to underpin household fuel and energy strategies with a good understanding of the mechanisms affecting household fuel use and fuel switching.

The purpose of this paper is to assess the determinants of household fuel choice and the scope of energy policy affecting it. A particular aim is to gather a better understanding of the relative importance of fuel substitution

 https://doi.org/10.1017/S1355770X04001858

and fuel complementation and the factors associated with this choice. Understanding household fuel choice is of vital importance in the search for policies to combat unsafe cooking practices. After reviewing theories of fuel choice, the article presents the results of a quantitative study of household fuel use in Guatemala. Guatemala was chosen because of the availability of an unusually detailed energy module in the household survey (ENCOVI, 2000). Unlike most other nationally representative household surveys which only identify one or two major cooking fuel(s), in ENCOVI 2000 respondents were asked detailed questions about their use of all energy sources. It therefore constitutes an attractive data source for studying fuel switching versus fuel stacking. Moreover, Guatemala is an interesting case because households use, to a varying extent, five different energy sources for cooking – wood, LPG, charcoal, electricity, and kerosene – implying active interfuel competition.

After this introduction, section 2 discusses theoretical approaches to household energy. Section 3 presents the data, followed by an analysis in section 4 of fuel use and fuel spending patterns. Section 5 presents a multinomial regression analysis of multiple fuel usage followed by conclusions and reflections on implications for energy policy in section 6.

2. Theories of household fuel choice

Household fuel choice has often been viewed in the past through the lens of the 'energy ladder' model. This model places heavy emphasis on income in explaining fuel choice and tends to focus on fuel switching. Recent years have seen a change towards emphasizing a multiplicity of factors as important for fuel choices, and to incorporate multiple fuel use based on the observation that households often choose to consume a portfolio of energy options at any one time.

The energy ladder model envisions a three-stage fuel switching process. The first stage is marked by universal reliance on biomass. In the second stage, households move to 'transition' fuels such as kerosene, coal and charcoal in response to higher incomes and factors such as deforestation and urbanization. In the third phase, households switch to LPG and electricity once their income is sufficient (Leach, 1992; Barnes, Krutilla, and Hyde, 2004). The simple energy ladder model is sometimes extended with more elaborate intermediate steps (Barnes and Floor, 1999).

The major achievement of the energy ladder model in its simplest form is the ability to capture the strong income dependency of fuel choices. Yet the ladder image is perhaps unfortunate because it appears to imply that a move *up* to a new fuel is simultaneously a move *away from* fuels used hitherto. The closely related concept of fuel switching suffers from exactly the same drawback: it embodies an implicit, as yet unproven belief that introducing a new superior fuel will phase out traditional fuels.

Evidence from a growing number of countries suggests that adoption of modern fuels often brings multiple fuel use (and greater total energy demand), resulting in households consuming a portfolio of energy sources at different points of the energy ladder (see for example Barnes and Qian, 1992; Hosier and Kipondya, 1993; Davis, 1998). This phenomenon has been termed fuel *stacking* (Masera, Saatkamp, and Kammen, 2000).[2] With much of the earlier literature focused on the energy ladder and fuel switching, the relative importance of fuel stacking versus fuel switching is not generally known. The causes of fuel stacking are also not well understood, although Masera, Saatkamp, and Kammen (2000) provide interesting insights from Mexican villages. Fuel stacking has important implications: To the extent multiple fuel usage is the norm, promotion of petroleum fuels may not displace traditional fuels, generating fewer benefits than sometimes hypothesized.

The energy ladder model provides little practical guidance as to how energy sector interventions can be designed to effectively promote welfare and health – what other factors besides income matter to fuel choice? A more policy relevant and realistic theory of household energy demand is thus necessary. A household economic model can help study responses to resource scarcities based on a theoretical framework for household decision making in circumstances where consumption and production decisions are interlinked (Dewees, 1989). According to the household economic framework, households maximize utility defined over consumption of final goods, leisure, and fuel attributes, subject to production functions (for cooking and agriculture) and time and income constraints. These constraints depend on the household's endowments of money, labor, and agricultural resources such as farm and common property land, trees, and animals.

Energy carries cash and opportunity costs. Electricity and petroleum fuels have start-up costs and consumption-dependent charges. With consumption credit usually very limited in developing countries, start-up costs often need to be financed via the current-period budget constraint. Biomass fuels collected or produced by the household itself carry the opportunity cost of using labor, land, and sometimes dung to provide energy. The time and budget constraints implicitly capture the opportunity costs. From the household's overall maximization problem, one can derive a 'reservation price' of biomass fuel. This is basically the opportunity cost to the household of biomass fuel when produced using the most efficient combination of labor and agricultural resources. Biofuels are sometimes commercial fuels and sometimes not, depending on transport and transaction costs. When households operate in fuel markets, their decision price is determined by the market price. For non-market participants, the decision price of biomass is the reservation price as determined by biomass availability and the opportunity cost of collection labor. The reservation price is specific to the household and unobservable (see Heltberg, Arndt, and Sekhar, 2000 for a formal model).

Empirical evidence based on the household economic framework strongly suggests that the reason for widespread collection of firewood in rural areas – even in places of mounting or severe scarcity of wood – is

[2] Foley (1995) suggested a ladder of energy demand rather than of fuel preferences. As incomes grow people start demanding more diversified energy sources since they can afford to purchase a variety of appliances that each require a specific energy source. However, the finding of widespread use of multiple fuels for cooking suggests genuine fuel stacking *for a given purpose* (see also Davis, 1998).

the very low opportunity cost of collection labor time (often female and child labor). Studies from Nepal have found that better off-farm labor opportunities are crucial for stabilizing forest levels, basically because off-farm wages set a downward limit on the opportunity cost of time. Rising labor cost may be the only factor capable of effectively regulating firewood supply from open access forests and commons (Bluffstone, 1995).

The combination of locally available biomass and low opportunity costs of collection labor time hinders uptake of commercial fuels in rural areas and small towns of low-income countries. Fuelwood becomes expensive where wood scarcity drives up its price or where rising opportunity costs of collection labor make self-collection unattractive. Once commercialized fuel markets exist, petroleum fuels can get their breakthrough if they can compete on price with fuelwood. City residents already paying for fuelwood are therefore the first to switch fuel. The nature of inter-fuel competition changes from price to quality competition once the purchasing power is comfortable (say in middle-income countries); natural gas, electricity and LPG stand to win that competition as the most convenient fuels. The convenience of modern fuels stems from time savings in fuel collection, cooking, and cleaning, smoke reduction, and the ability to adjust the flame. It is a very plausible conjecture that the time savings of modern fuels benefit females the most.

3. Household energy in Guatemala

This paper employs Guatemala's National Survey of Living Conditions (ENCOVI, 2000). The data set, which was collected during the year 2000, contains information on 3,424 urban and 3,852 rural households. Welfare comparisons are based on a measure of total household expenditure per capita that includes both cash expenditures and the imputed value of the household's home use of own production. All tables are based on nationally defined quintiles of expenditure per capita adjusted for spatial price variation, dividing the sample into five equal-sized groups of individuals. Since quintiles are not reformed by area, the bottom three quintiles have a large rural majority and the top quintile has a large urban majority.[3]

For each fuel, households were asked the total quantity consumed last month, the value of this consumption, and to provide a purpose breakdown. One can also distinguish purchased from self-collected wood and identify whether households are connected to the electricity grid. In addition, an accompanying community and price questionnaire provides price data at the community level for LPG, firewood, and kerosene. Compared with Living Standard Measurement Surveys (LSMS) undertaken in other

[3] Based on a national poverty line of US$1.5 per person per day, the total headcount is 56 per cent, with 25 per cent poverty in urban areas and 75 per cent poverty in rural areas. An ultra-poverty line was defined at 44 per cent of the poverty line, corresponding to US$0.66 per person per day, giving an ultra-poverty headcount of 11.3 per cent. Thus, when interpreting the tables in the following, it is useful to remember that the poor correspond to roughly the bottom three quintiles and the ultra-poor to half the bottom quintile.

countries, the present data set has much richer energy and fuel details, although there are also some problems, for example with the quantity information.

Firewood and health hazards

Cooking with solid fuels inside unvented houses results in smoke exposure. Elevated doses and durations of smoke exposure can have very serious health implications. Highest at risk are those who burn solid fuels in an all-purpose room (not a designated kitchen) so that all household members at home are exposed, and exposure is protracted beyond the duration of cooking. Exposure is lower when cooking outside the house.

One-quarter of the country's population resides in households that cook with firewood inside their house in a room that is not a partitioned kitchen. Exposure levels are likely to exceed safe levels for this group (of which less than one-fifth have a chimney). Most cooking in Guatemala is done by women, who spend 2–3 hours daily on cooking when using only wood (Torres, 2002). Women and the infants they are guarding are therefore the most exposed to smoke from solid fuels, although all people present during cooking are exposed to some extent. Mortality risk from indoor air pollution is known to be highest among children, the elderly, and the sick.

People cooking with firewood in a partitioned kitchen or in a separate building – more than half of the population – are also exposed to high levels of smoke, but their exposure is likely to be more confined to the cook(s) and during the time that cooking takes place. The poor are over-represented among firewood users cooking inside without partition. Indoor air pollution, however, is encountered in most income groups in both rural and urban areas.

All surveyed mothers were asked whether their infants had any cough, cold, bronchitis, breathing trouble, or respiratory infection during the last month.[4] Among wood users, 48 per cent of infants experienced some of these respiratory symptoms as compared with 43 per cent in households that did not use fuelwood (see table 1). Wood use is associated with increased prevalence of respiratory symptoms for almost all cooking arrangements.[5] And the highest prevalence of infant respiratory symptoms occur in households cooking with wood indoors in an unpartitioned room.

4. Patterns of energy expenditure and use

Table 2 shows median energy budget shares defined as the value of energy spending in proportion to total expenditures broken down by sector and quintile. Two sets of data are shown: (i) total value of all energy consumption[6] divided by total expenditures; and (ii) cash energy

[4] This is a broad group of symptoms, comprising both severe and mild cases, and it does not allow identification of acute respiratory infections. Restricting the analysis to acute respiratory infections, Torres (2002) finds similar effects of fuels and cooking arrangements on health outcomes.

[5] With the exception of the tiny group of people cooking in the open.

[6] For self-collected biomass, gifts, and consumption out of stocks, households were asked to report what the fuel would have cost had it been purchased. Almost

Table 1. *Infant respiratory symptoms by wood usage and cooking arrangement (in per cent)*

	Place of cooking				
	Inside		*Outside*		
	With partition	*No partition*	*Separate building*	*Open air*	*Total*
National					
Do not use firewood	43.7	42.6	33.5	87.3[a]	43.0
Use firewood	47.7	52.9	41.9	52.5	47.9

Note: Proportion of infants with respiratory symptoms (cough, cold, etc.) last month.
(a) This figure may not be representative due to very small sample size.
Source: Author's calculations based on ENCOVI (2000).

Table 2. *Median household expenditure share on energy (in per cent)*

	Quintile					
	1	*2*	*3*	*4*	*5*	*Total*
Urban						
All energy expenditures	9.8	10.5	9.2	6.9	4.3	5.7
Cash expenditures only	5.2	8.1	7.8	6.4	4.2	5.1
Rural						
All energy expenditures	10.2	8.9	7.9	7.4	5.4	8.2
Cash expenditures only	3.6	3.5	4.4	5.1	4.5	4.0
National						
All energy expenditures	10.1	9.1	8.5	7.0	4.5	7.1
Cash expenditures only	3.7	3.7	5.4	5.8	4.2	4.6

Note: Table shows household energy expenditures (including electricity and cooking fuels) in proportion to total expenditures. 'All energy' includes the imputed value of self-collected wood; 'Cash expenditures' excludes self-collected wood.
Quintiles are defined as equal number of individuals nationally.
Source: Author's calculations based on ENCOVl (2000).

expenditures. The difference between total and cash energy expenditure is the value of self-collected firewood.[7] It is hard to know exactly which criteria households used to self-assess the value of collected fuels. It is likely that

7 per cent of wood users, however, did not report any value of their firewood consumption. The figures on total budget share (but not those for cash outlays) are therefore biased downward for firewood consumers.

[7] Although the most extreme observations on budget share were omitted, the medians are reported here to avoid undue influence by outliers. Averages are higher.

most households have some knowledge of the market value of wood, but whether and how they factor in transport costs is uncertain.

The median energy budget shares are 7.1 per cent when self-collected fuels are included and 4.6 per cent for cash energy (averages are higher). Self-collected fuels are important for the poor and in rural areas, reflecting the low opportunity cost of time of these groups. In terms of cash energy expenditures, urban households consistently spend more of their budgets than rural households. Also, whereas the cash energy budget share is quite constant across quintiles in rural areas, some of the urban low-income groups spend relatively more of their income on commercial fuels than the upper quintiles. This is because the urban poor cannot substitute self-collection of biomass fuels for cash fuels. As a basic good, household energy is very important to the poor: the urban poor, in particular, are vulnerable when energy prices increase.

Fuel usage

Table 3 shows fuel usage by quintile and sector.[8] Electricity is the most commonly used energy source in urban areas, consumed by 95 per cent, followed by LPG which 78 per cent use; firewood is used by 46 per cent (two-thirds of which is bought), charcoal (25 per cent), while few use kerosene. In the poorest urban quintile, only two-thirds have electricity, LPG and charcoal usage is much lower, and firewood is universal. In rural areas, almost everybody uses firewood, one-third of which is bought, while 56 per cent use electricity, 41 per cent use kerosene, and only 20 per cent use LPG. When we look specifically at the rural poor, firewood is universal, much fewer have electricity, and instead kerosene is more important.

In order to get a better sense of how choice of cooking fuel corresponds to expenditure, the incidence of LPG and firewood usage is plotted in figure 1. The figure divides the rural and the urban samples into 4 per cent quantiles, yielding 25 groups of equal size with roughly similar per capita expenditure in each sector, and shows the average adoption rate of each fuel in each sector and 4 per cent quantile. In figure 2, usage of kerosene, charcoal, and electricity *for cooking purposes* is plotted against quantile average per capita expenditure.[9]

There are interesting differences in fuel uptake between urban and rural areas. At any level of expenditure, urban households are more likely to use LPG and rural households are more likely to use wood. LPG usage generally increases with expenditure (implicitly income). Urban LPG usage rises rapidly in a smooth and continuous manner from 6 per cent in the bottom 4 per cent to 25 per cent in the next-lowest quantile to almost everybody once per capita expenditures of US$3–4 per day (market exchange rate) are reached. At this level, LPG usage stabilizes above 80 per cent and cooking with electricity kicks in. In rural areas there is more of a clear threshold at around $1.5–2 per day, implying that the rural non-poor could

[8] All usage information is based on detailed fuel specific survey questions. Use is not made here of questions regarding ownership of stoves or other equipment.

[9] Non-cooking energy uses are ignored in this figure, something that mostly affects kerosene and electricity which are used more for lighting and appliances.

 https://doi.org/10.1017/S1355770X04001858

Table 3. *Usage rates of energy sources, by quintile and sector (in per cent)*

	Quintile					
	1	*2*	*3*	*4*	*5*	*Total*
Urban						
Electricity	66.6	83.1	90.8	97.0	99.1	95.5
LPG	6.7	24.6	58.9	81.4	91.8	77.9
Kerosene	28.3	12.3	7.4	4.3	1.5	4.4
Charcoal	2.0	6.8	11.1	18.9	34.7	24.7
Firewood (all sources)	97.5	90.7	76.0	60.3	23.0	46.4
Firewood (cash only)	38.4	49.9	49.6	42.3	16.8	30.7
Rural						
Electricity	31.3	49.7	64.7	72.7	78.0	56.2
LPG	1.3	5.8	17.7	40.9	64.8	20.2
Kerosene	60.1	47.0	34.2	24.8	23.3	40.5
Charcoal	0.7	1.3	2.7	6.6	13.1	3.7
Firewood (all sources)	99.6	99.4	97.5	93.0	77.2	95.5
Firewood (cash only)	22.7	26.9	40.3	40.1	37.3	32.5
National						
Electricity	34.2	55.1	73.0	85.0	94.6	73.1
LPG	1.7	8.9	30.7	61.4	86.2	45.1
Kerosene	57.5	41.3	25.7	14.4	6.1	24.9
Charcoal	0.8	2.2	5.4	12.8	30.2	12.7
Firewood (all sources)	99.5	98.0	90.7	76.4	34.3	74.4
Firewood (cash only)	23.9	30.7	43.3	41.2	21.1	31.7

Note: Table shows the proportion of households using each fuel, irrespective of purpose.
Source: Author's calculations based on ENCOVI 2000.

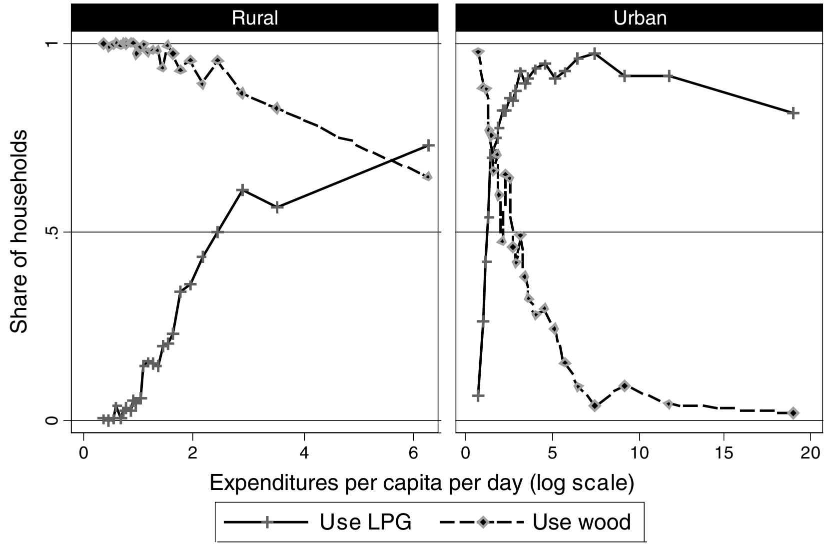

Figure 1. *Usage of LPG and firewood*

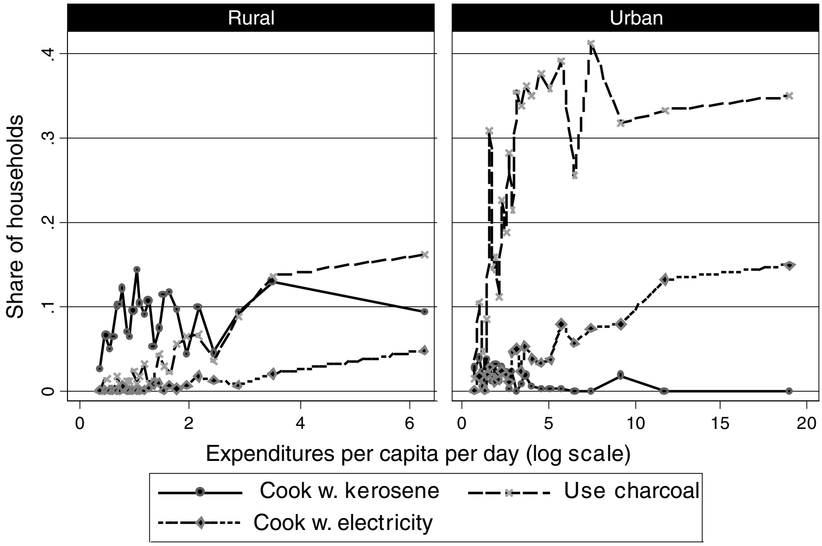

Figure 2. *Usage of kerosene, charcoal, and electricity for cooking*

be realistic targets for LPG. Only the rural top 16 per cent, however, have LPG penetration above 50 per cent

Figure 1 also shows the response of firewood use to rising income. The incidence of rural firewood usage remains high almost universally. Firewood use only declines to a very limited extent in the top end of the rural income distribution. This suggests fuel stacking to be the most common response to growing income in rural areas. Urban firewood usage decreases rapidly with expenditure. Instead, charcoal for cooking plays a strong role for the urban middle class (figure 2). For them, LPG–charcoal fuel stacking is common. Electricity is used as a cooking fuel only in a few of the highest income urban groups. Kerosene use for cooking is very marginal in Guatemala.

Engel curves for LPG and firewood

Data on the quantity of fuels consumed by households give much the same picture as the data on usage. Figure 3 shows fuel Engel curves: quantity (in log form) of LPG and firewood averaged over all households (in each sector and 4 per cent quantile), irrespective of whether they use the fuel or not. In rural areas, the average quantity of firewood remains constant in almost all income groups, despite growing amounts of LPG. In urban areas, the amount of firewood tends to decline for the top half of households. The lower half use almost as much firewood as rural households. Thus, wood quantity does not decrease in tandem with growing LPG.

Table 9 in the appendix reports the results of a set of Engel curve regressions. These are Tobit estimates of quantity of fuel used.[10] Fuel

[10] Quantities are in logarithmic form and per household.

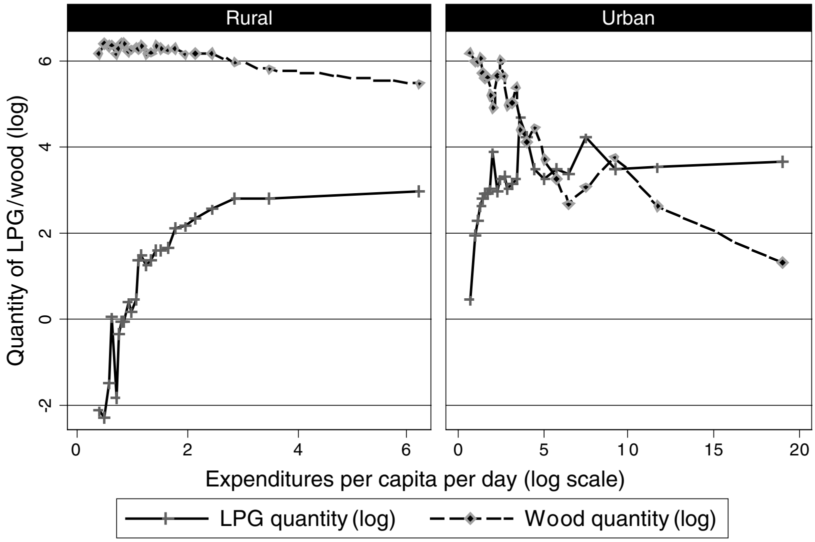

Figure 3. *Engel curves for LPG and firewood*

quantities are regressed on log expenditures, log expenditures squared, fuel prices, a number of household characteristics, and regional dummies. The results confirm that increasing per capita expenditures have a different impact on fuel consumption in urban and rural areas. Rural consumption of LPG and firewood both increase with per capita expenditures for most expenditure groups, with wood quantities peaking earlier than LPG. In urban areas, the quantity of wood declines except in the lower expenditure groups. LPG instead increases over a good deal of the urban expenditure range.

The regressions also suggest fuel prices can be drivers of inter-fuel substitution. In rural areas, the price of LPG is significant for LPG and wood demand with the expected signs; and the price of firewood has a significant negative impact on firewood demand in both sectors. Household size is associated with fuel stacking – larger households use more of both fuels. Education has a very significant impact on fuel choice in terms of discouraging wood and enhancing LPG demand. Having electricity also promotes fuel switching. Farmers and ethnic indigenous groups show the opposite tendency: they use more wood and less LPG, everything else equal.[11]

Household portfolios of cooking fuels

As already mentioned, multiple fuel use is fairly common. Table 4, for example, documents that slightly less than half of all urban households use multiple fuels; their combinations evolve around LPG, wood, and to a lesser

[11] These results are in line with results from other countries based on the incidence of usage (Heltberg, 2004).

Table 4. *Summary of cooking fuel groups* (*Share of households in groups in per cent*)

	Urban	*Rural*	*Total*
Single fuel users	52.2	73.4	64.2
Multiple fuel users	47.8	26.6	35.8
Combinations involving:			
LPG	77.7	20.2	44.9
Kerosene	1.4	8.6	5.5
Wood	45.3	95.3	73.8
Electricity	4.0	0.6	2.0
Charcoal	24.3	3.4	12.4

Source: Author's calculations based on EHCOVI 2000.

extent charcoal. In contrast, one-quarter of rural households use multiple fuels, one of which is usually firewood.[12] It seems LPG adoption is often associated with fuel complementation: 57 per cent of urban and 87 per cent of rural LPG users also cook with other fuels (wood or charcoal).

The widespread combination of wood and LPG is not readily explicable by the energy ladder model: these fuels are at the bottom and the top, respectively, of the energy ladder. Why would so many households with access to LPG want to continue using wood? Why do so many urban LPG users also use charcoal? I return to this question below.

First, however, it is important to establish that fuel stacking is a common phenomenon, not an exception. Figure 4 shows the average number of cooking fuels per household in each sector and 4 per cent quantile. In rural areas, the number of cooking fuels in the portfolio grow with welfare (from below 1.5 to 2 per household). In urban areas, there is more of an 'inverse U' with the number of fuels initially increasing (to more than 2). The middle groups have high occurrence of LPG, charcoal, and firewood. The decline in the number of fuels at the top end of the income distribution corresponds to fuel displacement. Summing up, fuel stacking or complementation appear to dominate in rural areas and in the urban bottom half or so. Fuel switching really only appears to start at per capita expenditures above US$4 per day (market exchange rate).

A closer look at firewood and LPG

In order to assess the affordability of individual fuels, table 5 shows the average total value spent by households on each fuel, conditional on use (cash outlays for purchased energy sources, imputed values for collected firewood). Mean spending refers to users only.[13] The largest energy

[12] The most common combinations of cooking fuels are, in order of national importance: wood only, wood and LPG, LPG only, charcoal and LPG, kerosene and wood, and charcoal, wood, and LPG.

[13] Averages are taken over non-missing and non-zero values. The general conclusions do not depend on whether the figures are presented on a per household or a per capita basis.

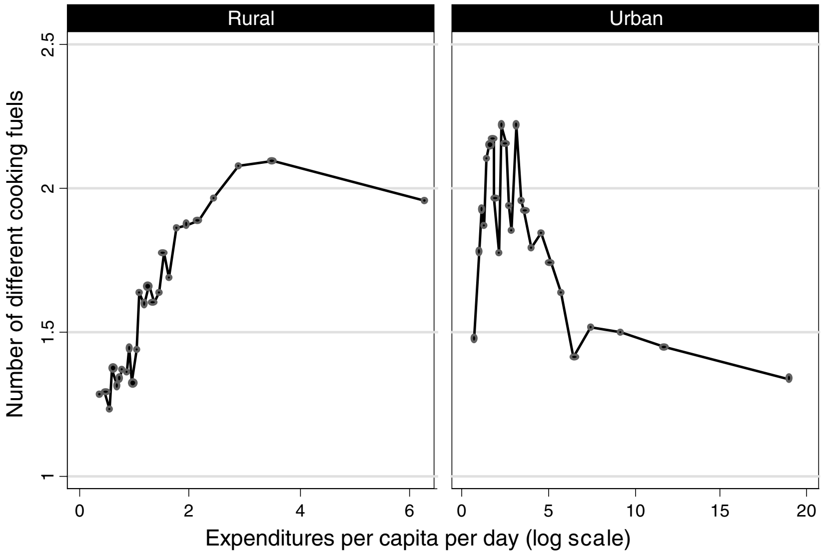

Figure 4. *Average number of cooking fuels*

expenditure items are firewood, electricity, and LPG. Firewood represents the single largest energy expenditure item except for the top quintile: wood purchasers spend on average 85 Q. per month buying wood, more than the average electricity or LPG bill. LPG spending is also substantial among its users, while electricity spending is large for the best off and relatively modest for others.

It is remarkable how much households in the lower quintiles appear to be spending on purchasing firewood in the market. Although the proportion of wood users who purchase it rises with total expenditure and urbanization, substantial numbers of poor and rural also purchase fuelwood – for example, 24 per cent nationally of households in the bottom and 31 per cent in the second quintile purchase wood. Many non-poor also consume firewood: in the top quintile, 23 per cent of urban and 77 per cent of rural households use wood. It is also surprising to note that wood purchasers appear to be spending more in absolute terms on purchasing wood every month than LPG users spend buying LPG. This issue is explored in the following.

An attempt was made to compare the relative affordability of LPG versus firewood. It was infeasible to calculate the cost per unit of effective energy for woodfuel because of uncertainties about bundle sizes and energy content of firewood in the ENCOVI survey.[14] An alternative approach to energy cost comparison was adopted (see table 6). This approach compares

[14] Using different data, however, Foster and Tre (forthcoming) estimate that firewood and LPG cost the same in Guatemala per unit of net effective energy, but reckon that the upfront capital costs of LPG still make the poor prefer firewood.

 https://doi.org/10.1017/S1355770X04001858

Table 5. *Household energy ependitures by energy sources (conditional on use) (in Quetzales/month/household)*

	Quintile					
	1	*2*	*3*	*4*	*5*	*Total*
Urban						
Electricity	35.6	41.6	59.3	74.9	150.8	110.4
LPG	55.7	63.8	63.4	64.8	80.7	74.2
Kerosene	19.3	14.5	17.7	14.6	9.0	15.1
Coal	2.0	4.6	10.5	10.3	11.4	10.9
Firewood (all sources)	72.4	89.2	101	82.3	77.9	85.7
Firewood (cash only)	87.1	104.2	96	94.5	89.1	94.1
Rural						
Electricity	34.2	28.9	39.2	51.5	89.1	46.3
LPG	60.2	64	66	64.9	72.1	67.3
Kerosene	10.4	10.6	13	13.5	11.7	11.4
Coal	20.8	5.7	5.5	15	13.5	12.3
Firewood (all sources)	74.5	86.1	90.7	85.6	88.7	84.5
Firewood (cash only)	85.1	111	108.3	98.2	120.5	104.2
Total						
Electricity	34.4	32	47.1	65.1	140.1	82.3
LPG	58.7	63.9	64.4	64.8	79.4	72.4
Kerosene	10.8	10.7	13.4	13.6	11.2	11.7
Coal	17.1	5.1	8.8	11.5	11.6	11.2
Firewood (all sources)	74.3	86.6	93.5	84.3	83.1	84.8
Firewood (cash only)	85.4	109.2	103.8	96.3	100.8	100

Note: Table shows expenditures in Quetzales/month/household averaged over users.
Source: Author's calculations based on ENCOVI 2000.

actual fuel spending by different fuel user groups: households using only LPG, only cash wood, both LPG and cash wood, and both LPG and charcoal. Average actual fuel spending by each of these groups indicates the costs of satisfying normal household cooking needs using LPG, wood, charcoal, or a combination. Given differences in economic position and household size between fuel groups, comparison is made quintile for quintile in urban areas only, looking at cash fuel spending per household, fuel spending per capita, and fuel budget share.

The group that uses both LPG and wood tends to have the highest fuel spending in most quintiles, regardless of whether comparison is made for fuel spending in total, per capita, or as a share of total expenditures. Households using only wood tend to spend almost as much as the LPG–wood group (and in fact spend slightly more in the third urban quintile and the same in the fourth).[15] Households using only LPG or LPG–charcoal

[15] The puzzling finding that many households apparently spend more on purchasing fuelwood than it would cost them to buy LPG may not hold if there is a downward bias on reported LPG expenditures. This in turn would be the case if the actual consumption was more than 1 cylinder a month (11.4 kg) and the number of

Table 6. *Energy expenditures by users of LPG and cash wood Urban Guatemala: Average per household and per capita fuel expenditures (Q/month.)*

	LPG only	*Wood only*	*LPG & Wood*	*LPG & Charcoal*
1st urban quintile				
Total fuel spending	60	109	159	64
Per capita fuel spending	11	18	24	17
Fuel budget share (%)	3.8	7.8	8.4	6.2
2nd urban quintile				
Total fuel spending	65	115	145	70
Per capita fuel spending	15	27	27	14
Fuel budget share (%)	3.3	5.9	6.1	3.4
3rd urban quintile				
Total fuel spending	66	152	150	71
Per capita fuel spending	18	45	34	16
Fuel budget share (%)	2.6	6.6	5.0	2.3
4th urban quintile				
Total fuel spending	74	150	148	80
Per capita fuel spending	24	46	45	22
Fuel budget share (%)	2.2	4.4	4.3	2.0
5th urban quintile				
Total fuel spending	88	106	141	107
Per capita fuel spending	38	59	97	31
Fuel budget share (%)	1.6	2.4	4.8	1.3

Note: Only cash expenditures are included. Comparison is made across four groups of households defined in terms of the cooking fuel(s) they use.

spend substantially less on fuel. The magnitude of fuel spending in both the LPG–wood group suggests a far greater role for wood than merely as an occasional backup during LPG cylinder refill.

Therefore, wood is not a cheap fuel when procured from the market. Users of purchased wood – alone or in conjunction with LPG – tend to spend more on fuel than those who cook only with LPG. In other words, cooking with purchased wood may not be cheaper than LPG. Thus, we need to look beyond cost factors to understand why so many continue to use wood, and especially the large number of households who purchase it. If those factors can be identified and targeted in energy interventions, there would be a large potential market for LPG. In fact, all of those who presently pay for their wood can be considered potential candidates for switching entirely to LPG. This is the case for 31 per cent of all households (similar in urban and rural areas). In the group of wood purchasers, only 45 per cent already consume LPG. In the following, it is investigated further what may constrain the spread of LPG.

households consuming more than 1 cylinder a month exceeds the number of households using less than 1 cylinder (both rounding to 1 in the response). This scenario is plausible given that in some other countries those who use LPG as their primary cooking fuel have been found to use something like 15 kg per month.

Table 7. *Characteristics of urban single fuel and mixed fuel households*

	LPG Only	*LPG-Wood Mix*
Number of households	317,866	239,866
Household expenditure per capita	15,340Q	7,788Q
Household size	3.9	5.3
Share residing in metropolitan city	67.5%	34.1%
Share residing in other urban areas	32.5%	65.9%
Spending on food outside the house	53.2Q	18.2Q
Frequency of cooking maize		
Not often	88.2%	34.1%
Daily	3.0%	34.5%
Twice a week	3.6%	15.3%
Weekly	0.4%	4.2%
Other frequency	4.7%	11.9%
Total	100.0%	100.0%

Source: Author's calculations based on ENCOVI 2000.

Joint LPG–wood use is especially intriguing in urban areas where wood tends to be commercialized and using wood adds considerably to the household fuel bill. Is multiple fuel usage simply a transitional phenomenon caused by a lag from the time LPG is adopted until other fuels are abandoned? It turns out not to be the case – many households that have consumed LPG for more than two years continue using wood, albeit at a slightly lower rate than new LPG users. The start-up costs of LPG are often mentioned as an important barrier for greater LPG uptake. Including the cost of the cylinder (which comes with a small amount of LPG) and the stove, households would in 2002 need to pay US$54–60 to adopt LPG (Matthews, 2002). It is hard to say for how many households this imposes a significant constraint on uptake over and above the problem of paying for current consumption of LPG.

The vast majority of people have neighbors in their community that consume LPG. Also, according to the price and community questionnaire, the vast majority of households appear to have access to LPG. It is therefore unlikely that complete geographic isolation from LPG distribution centers is blocking many households from adopting LPG.

Another explanation sometimes put forward relates to the role of cultural factors, lifestyle, and cooking habits. Table 7 compares salient characteristics of that part of the sample that is (i) urban and (ii) use either LPG-only or LPG–wood. There are clear differences between these two groups. The table shows that most LPG-only households live in the Metropolitan city whereas more than half the other group lives in other and smaller towns. LPG-only households are smaller and better off. The lifestyle in a big city is different. For example, households that use only LPG spend much more on food outside the house. This could suggest they often purchase tortillas and hence do not need to burn wood in order to eat wood-baked tortillas, the staple diet of Guatemala. This conjecture is supported by the fact that those who complement LPG with wood cook maize much more often than LPG-only households. It seems plausible that LPG-only households have a different lifestyle and avoid wood by purchasing wood-baked products (tortillas).[16]

5. Joint LPG and wood use: multinomial logit analysis

A more formal analysis of what determines the most important combinations of cooking fuels was also carried out, using multinomial logit. Multinomial logit is a regression technique used to assess factors associated with households' choice among mutually exclusive groups. Focus is here on the most important groups: LPG-only, wood-only, and joint wood–LPG. In urban areas, the LPG–charcoal combination is also considered. Eighty-seven per cent of households belong in one of these groups. The joint wood–LPG group is used as omitted category.[17] The model for multinomial logit is

$$\Pr(Y = j) = \frac{e^{\boldsymbol{\beta}'_j \boldsymbol{x}_i}}{1 + \sum_{k=1}^{J} e^{\boldsymbol{\beta}'_k \boldsymbol{x}_i}} \quad \text{for } j = 1, 2, \ldots, J.$$

where there are J outcomes, $\boldsymbol{x}$ is a vector of explanatory variables, and $\boldsymbol{\beta}_j$ is a vector of parameter estimates associated with outcome j.

The explanatory variables were selected in order to stay as close as possible to the theoretical framework and its implications as outlined in section 2. The first group of regressors includes variables such as log per capita expenditures, log prices of LPG, kerosene, and firewood, and log household size to account for economies of scale. These are core explanatory variables that belong in any demand equation on *a priori* theoretical grounds. The variables in the second group include the share of females in the household to control for gender-specific labor sharing and female bargaining power; distance to usual source of firewood (in meters) averaged over all members in the community and in log form. Together with a dummy for farm households, this is intended to capture the opportunity cost of firewood collection; dummies for whether the maximum education of any household member is primary, secondary, or post-secondary (with no household member having completed primary education the omitted category); access to electricity (grid connection) to capture derived effects from electricity to other fuels; dummy for households belonging to an indigenous ethnic group (mostly Maya); number of rooms in the house, since space heating and cooking are often joint; and a regional dummy for each of Guatemala's seven major geographic areas.

[16] If this is correct, firewood use migrates from households to tortilla bakeries. This may be good for overall exposure to woodfuel smoke if bakeries are better ventilated than the average private home. The cultural norm of preparing certain dishes using wood, and the reluctance by less-affluent households from smaller urban areas to substitute purchased tortillas for home-baked tortillas, appear significant for maintaining wood in the household fuel mix. Similar observations have been made in India concerning traditional oven-baked breads.

[17] The choice of omitted category does not affect results. It merely influences how parameters are to be interpreted.

Estimated parameters are presented as relative risk ratios (that is, as e^{β_j}). Parameters greater than one indicate the regressor is associated with a probability of the outcome that is greater than the probability of the base case (ceteris paribus). Parameters below one indicate that the variable is causing the outcome to have a smaller probability than the base case. For example, a significant parameter below one for wood-only therefore suggests the variable is causing adoption of LPG since it causes households to move out of the wood-only group. Likewise, a significant parameter above one in the LPG-only equation means a move away from wood.

Results are shown in table 8. In urban areas, higher expenditure is associated with a significant move away from wood and into LPG. The top income bracket complements LPG with charcoal. Expenditures are insignificant for fuel switching in rural areas. Prices matter to some extent: high LPG prices increase the chance of consuming just wood in rural areas, and high firewood prices increase the probability of using LPG only in urban areas. These results are symmetric in the sense that wood dominates rural cooking with LPG an occasional complement, whereas LPG dominates urban cooking with wood as a complement. High price of the complement lessens its use, as predicted by basic theory.

Household size is insignificant for the probability of using wood as the only fuel (relative to the base case, both wood, and LPG). Small households are more likely to use LPG as their only fuel (they also use a smaller overall number of fuels), consistent with the idea that the relative labor scarcity of these households translates into high opportunity costs of wood collection. The gender composition of the household has a similar effect – a high share of females significantly reduces the likelihood of single fuel LPG, while it does not affect the choice between only wood and joint wood/LPG. A high share of females increases the supply of collection and cooking labor time and hence reduces the need to abandon time-consuming fuelwood. This is in contrast to what one would have expected from considerations of bargaining power – assuming additional females translates into a better female bargaining position – as the benefits from using LPG presumably derive mainly to women.

Education is a strong determinant of fuel switching. The more education, the larger is the probability of using only LPG (significant in both urban and rural areas) and the smaller is the chance of using only wood (significant in urban areas only). The reason may be that education increases the opportunity cost of collection time. In urban areas the number of rooms is significantly associated with switching away from wood and into LPG exclusively. This is presumably a wealth effect, as considerations of demand for heating energy would have led to the opposite conclusion. Being a farm household has the opposite effect: farmers are less likely to use only LPG (significant everywhere) and more likely to use only wood (significant in urban areas only). This is likely caused by low opportunity costs of woodfuel to farmers.

Indigenous ethnic groups have a fuel portfolio that is significantly different only in urban areas, resulting in a much higher likelihood of using only fuelwood. This mirrors the Engel curve findings of larger quantities of firewood and less LPG in this group. Several conjectures are available

Table 8. *Multinomial logit analysis of wood/LPG combinations (Omitted category: both LPG and woodfuel)*

	Urban						*Rural*			
	Only LPG		*Only wood*		*LPG & Charcoal*		*Only LPG*		*Only wood*	
Variable name	β	*z-stat*	β	*z-stat*	β	*z-stat*	β	*z-stat*	β	*z-stat*
Expenditures per capita (log)	2.70	7.27	0.18	−10.80	5.35	0.93	1.11	0.37	0.09	0.02
LPG log price of	1.44	0.48	1.97	0.83	0.57	0.56	0.37	−0.76	3.01	2.05
Kerosene log price	0.60	−1.44	0.62	−1.43	1.13	0.55	0.18	−3.51	1.75	0.51
Firewood log price	1.47	2.58	1.03	0.19	1.53	0.29	1.37	1.07	1.01	0.17
Log household size	0.47	−4.79	0.77	−1.52	1.18	0.25	0.25	−4.49	0.43	0.08
Primary education	2.21	2.12	0.47	−2.88	0.92	0.49	1.94	0.84	0.33	0.10
Secondary education	3.92	3.61	0.27	−4.65	1.74	0.92	4.96	1.95	0.17	0.05
Post-secondary education	4.94	4.01	0.21	−4.33	1.49	0.83	12.88	2.91	0.20	0.09
Number of rooms	1.08	1.91	0.85	−3.20	1.11	0.05	1.12	1.22	0.71	0.04
Farm household	0.15	−9.20	2.54	6.64	0.16	0.05	0.22	−5.32	1.91	0.26
Share of females in household	0.46	−2.83	0.89	−0.35	0.41	0.14	0.19	−3.07	0.45	0.13
Indigenous	0.52	−4.14	1.75	3.92	0.42	0.10	0.96	−0.12	1.34	0.20
Community median firewood distance	1.03	1.54	1.04	1.73	1.03	0.03	0.93	−1.69	1.14	0.03
Electrified	1.80	1.19	0.36	−4.25	–	–	2.31	1.99	0.44	0.07
North	0.27	−5.06	2.17	2.17	0.15	0.05	0.14	−2.77	1.13	0.44
Northeast	0.43	−3.55	3.62	3.46	0.47	0.13	0.65	−0.89	0.56	0.20
Southeast	0.31	−4.86	2.01	1.95	0.19	0.06	0.33	−2.33	0.87	0.28
Central	0.31	−5.14	1.34	0.87	0.36	0.10	0.73	−0.78	0.57	0.17
Southwest	0.42	−4.05	1.23	0.62	0.18	0.05	0.25	−2.90	0.66	0.20
Northwest	0.21	−6.07	1.71	1.58	0.18	0.06	0.22	−1.69	1.97	0.68
Peten	0.13	−6.37	3.98	3.44	0.04	0.02	1.10	0.13	1.11	0.46
Observations/Pseudo R-squared	2845/0.34						3385/0.41			

Note: β refers to the estimated parameter for the relative risk ratios. Values below one indicate smaller chance of belonging to group, values above one higher chance, relative to the omitted category which is joint wood and LPG.
Source: Author's calculations based on ENCOVI (2000).

to account for this finding: a traditional lifestyle and other cultural factors may lead to a preference for fuelwood among indigenous groups; or it may be that this group is less integrated into the formal economy and finds it harder to afford or access LPG. Distance to fuelwood source does not appear important in this specification.

Having electricity is found to be associated with fuel switching. In urban areas, it results in a significantly smaller probability of using only wood and more LPG usage. In rural areas, it causes a significantly larger probability of consuming only LPG. Hence, the electrification results here confirm the existence of a correlation between electricity and fuel switching, although the results are unable to distinguish between causation and association. Barnes *et al*. (2004) were the first to report the same finding for a sample of urban respondents around the world, while Heltberg (2003) documents a significant impact of electrification on fuel switching for both urban and rural households in eight developing countries.

Barnes *et al*. (2004) suggest two possible explanations for the electricity–LPG link: (i) 'where electricity is available, fewer barriers constrain other modern fuels as well' and (ii) 'availability of lighting and other appliances spurs people to a greater acceptance of modernity and modern fuels'. One could add to this two additional possibilities: (iii) that areas that are in some sense more 'modern' (for example large as opposed to small towns and places with better infrastructure) get connected first to the electricity grid. These areas are also more motivated to adopt modern fuels. If this is the case, the regression results of electrification merely reflect a joint correlation rather than a causality; expanding electricity to unconnected areas will not, in itself, cause people to also adopt LPG. Finally, (iv) assume that energy needs are organized in a hierarchy where electricity is the most desired innovation and modern fuels follow further down the list of priorities. Households without grid connection may be unmotivated to adopt LPG – they would skip a ladder in the hierarchy of needs. In this case grid expansion does in fact have an independent, causal effect on LPG uptake.

The regional dummies mostly indicate less exclusive reliance on LPG relative to the omitted region, the metropolitan area. They also suggest greater probability of using wood-only (significant in urban areas of some of these regions).

6. Implications for energy policy

This paper has analyzed patterns of fuel use, fuel spending, and fuel switching in Guatemala using detailed energy-specific information from a recently compiled nationally representative household survey data set. LPG (bottle gas) is used mostly by the top half of the population, and predominantly in urban areas. Poor and rural households continue to rely largely on firewood for cooking with electricity (where available) and otherwise candles or kerosene for lighting. This section reflects on the lessons for energy policy – in Guatemala and other developing countries – from the analysis.

As a basic good, many poorer households tend to spend a disproportionate large share of their budget on energy. Many of Guatemala's rural poor rely on self-collected fuelwood, however, and are therefore able to keep their cash energy expenditures down to around 3–6 per cent of total expenditures. But many urban low-income groups do not have the option of collecting wood, and often spend 8 per cent or more of their budgets on household energy (cooking fuel and lighting). Wood purchases are an important component of energy expenditures for many urban low–income groups but also for a surprising number of rural households. Prices of energy – electricity, modern fuels, and firewood – therefore have severe implications for the purchasing power of many urban and some rural low-income groups. As discussed in the introduction, energy use also affects household welfare through a variety of other channels, including indoor and outdoor air pollution, human productivity, and degradation of forests and soil.

Affordability is a key constraint for more rapid expansion of modern energy services throughout the developing world. Donors and governments in many countries are struggling to re-define the proper role of energy price subsidies (Guatemala does not have such subsidies). The policy aim of greater uptake of modern energy and the problems of affordability of modern energy services can make energy subsidies seem appealing. Yet the profile of LPG consumption in Guatemala (and quite a few other developing countries) is such that public support for LPG would be regressive. Subsidizing current consumption of fuel or electricity often has the drawback of draining funds away from service expansion, which means that the poor, who are more likely to lack a connection in the first place, end up being supply constrained. Guatemala has implemented interesting policies to support the expansion of electricity connections to disadvantaged rural communities.

Moreover, LPG subsidies may not induce households to abandon fuelwood. LPG uptake often goes hand-in-hand with continued wood usage, and many factors apart from prices matter for fuel choice. For example, traditional cooking techniques and taste preferences sometimes make people prefer wood even when wood is as expensive as available alternatives. Upfront costs of commencing use of LPG also seem to play a role in limiting uptake. Fuel policies – whether concerned with indoor air pollution or forest degradation – need to look beyond simple pricing instruments to a wider array of policy options. The analysis in this paper helps point to some of the factors associated with fuel choice, which policies need to consider. Another lesson, however, is that the currently available household energy technologies tend to be too costly for many low-income households. Problems of affordability affect both current use and service expansion. The implication is a need to emphasize more research and innovation to search for low-cost household energy technologies defined broadly as grid and non-grid electricity, cooking fuels, and cooking technologies.

Regarding the factors associated with fuel choice, the analysis in this paper confirms that household income exerts a robust influence on fuel choice. In urban areas rising household expenditures often – but far from universally – induces fuel switching, particular in the upper half. Multiple fuel usage or fuel stacking is a more common response in rural areas.

The average quantity of firewood is almost constant through most of the rural income distribution, and in fact only the very best off in rural areas abandon wood. Education and electrification appear to be instrumental for fuel switching. Large household size and many females translate into low opportunity costs of collecting and using firewood and therefore often lead to fuel stacking. Ethnicity, prices, and region of residence also matter for fuel choice. Many of these factors can be understood in terms of how they affect the opportunity costs of collecting and using firewood. Education, for example, increases the opportunity cost of time and therefore makes the time savings to be gained from modern fuels more attractive. The role of cultural factors, taste preferences, and cooking habits, however, is difficult to capture theoretically and assess quantitatively. Education and big city life undoubtedly play a role in speeding up cultural change, including adoption of new fuels and new cooking techniques, and abandonment of traditional ones.

Energy policies for development should be based on the realistic proposition that firewood will remain responsible for fully or partly meeting household cooking needs for very substantial proportions of the world's population. This should not lead to complacency. Efforts to promote safe and efficient household energy are needed, but such efforts should not rely exclusively on fuel switching. An appropriate balance needs to be developed between policies aiming at inter-fuel substitution and policies seeking to ameliorate the negative consequences of woodfuel. Low-cost innovations need to be encouraged. Interventions must be found to make solid fuels less risky for health. Although analysis of such interventions was outside the scope of this article, candidates include improved stoves and awareness campaigns seeking to spur better ventilation or outdoor cooking.

Energy policies should be carefully targeted to relevant segments. Improved stoves should only be promoted in areas where wood is plentiful. Support for LPG uptake needs to be targeted to areas where wood is expensive. Energy policies should promote choice, innovation, and cost-effectiveness by removing barriers to access, where such barriers exist, and consider lowering uptake costs.

References

Barnes, D. and W. Floor (1999), 'Biomass energy and the poor in the developing countries', *Journal of International Affairs* **53**: 237–259.

Barnes, D.F., K. Krutilla, and W. Hyde (2004), 'The Urban Energy Transition – Energy, Poverty, and the Environment', Forthcoming book volume, in press.

Barnes, D.F. and U. Qian (1992), 'Urban interfuel substitution, energy use and equity in developing countries', World Bank Industry and Energy Department Working Paper, Energy Series Paper 53, Washington, DC.

Bluffstone, R. (1995), 'The effect of labor market performance on deforestation in developing countries under open access: an example from rural Nepal', *Journal of Environmental Economics and Management* **29**: 42–63.

Bruce, N., L. Neufeld, E. Boy, and C. West (1998), 'Indoor biofuel air pollution and respiratory health: the role of confounding factors among women in highland Guatemala', *International Journal of Epidemiology* **27**: 454–458.

Davis, M. (1998), 'Rural household energy consumption: the effects of access to electricity – evidence from South Africa, *Energy Policy*. **26**: 207–217.

Dewees, P.A. (1989), 'The Woodfuel crisis reconsidered: observations on the dynamics of abundance and scarcity', *World Development* **17**: 1159–1172.
Eckholm, E. (1975), 'The other energy crisis: firewood', Worldwatch Institute, Washington, DC.
ESMAP (2000), 'Energy and Development Report 2000: Energy Services for the World's Poor', Washington, DC.
ESMAP (2001), 'Sustainable woodfuel supplies from the dry tropical woodlands', ESMAP Technical paper 13, June, Washington DC.
FAO (Food And Agriculture Organization Of The United Nations) (1996) (reprint), 'Forests, fuel and the future – wood energy for sustainable development', Forestry topics report no. 5, Rome.
Foley, G. (1995), 'Photovoltaic applications in rural areas of the developing world', World Bank Technical paper no. 304, Energy Series, Washington DC.
Foster, V. and J.-P. Tre (Forthcoming) 'Measuring the impact of energy interventions on the poor – an illustration from Guatemala'.
Heltberg, R. (2001), 'Determinants and impact of local institutions for common resource management', *Environment and Development Economics* **6**: 183–208.
Heltberg, R. (2004), 'Fuel switching: evidence from eight developing countries', *Energy Economics* **26**: 869–887.
Heltberg, R., T.C. Arndt, and N.U. Sekhar (2000), 'Fuelwood consumption and forest degradation: a household model for domestic energy substitution in rural India', *Land Economics*, May.
Hosier, R. and W. Kipondya (1993), 'Urban household energy use in Tanzania: prices, substitutes and poverty', *Energy Policy* **21**: 453–473.
IEA (International Energy Agency) (2002), *World Energy Outlook 2002*, Paris.
Leach, G. (1992), 'The energy transition', *Energy Policy* (February): 116–123.
Masera, O.R., B.D. Saatkamp, and D.M. Kammen (2000), 'From linear fuel switching to multiple cooking strategies: a critique and alternative to the energy ladder model', *World Development* **28**: 2083–2103.
Matthews, W.G. (2002), 'LPG for household use in Guatemala: final report', Consultancy report submitted to the World Bank, September.
Smith, K.R. (1999), 'Indoor air pollution'. Pollution Management In Focus, Discussion Note Number 4, August, World Bank.
Smith, K.R. (2002), 'In praise of petroleum', *Science*, 6 December.
Torres, J.E. (2002), 'Does fuelwood smoke endanger infant health? Evidence from DHS and LSMS surveys in Guatemala', Consulting report to the World bank, January.
WHO (2002), *World Health Report 2002*, Geneva.
World Bank (1996), Rural energy and development: improving energy supplies for two billion people: development in practice, Washington, DC.

Appendix

Table 9. *Engel curve regressions for firewood and LPG (Tobit estimation of quantity of fuel used – log)*

	Rural firewood (log)	*Urban firewood (log)*	*Rural LPG (log)*	*Urban LPG (log)*
Per capita expenditures, log	3.657	6.677	23.159	12.712
	(12.02)**	(6.53)**	(10.87)**	(20.40)**
Per capita expenditures, log squared	−0.865	−1.691	−2.686	−1.606
	(14.02)**	(9.94)**	(7.40)**	(17.55)**
Log price of LPG	0.954	−0.301	−4.593	−0.105
	(2.26)*	(0.21)	(2.30)*	(0.13)
Log price of kerosene	0.634	0.817	−1.751	0.709
	(3.57)**	(1.26)	(2.01)*	(1.78)
Log price of firewood	−0.290	−1.154	0.185	0.167
	(3.14)**	(4.10)**	(0.41)	(1.01)
Household size, log	0.672	1.306	3.335	0.690
	(7.30)**	(4.70)**	(7.54)**	(4.34)**
Primary education[a]	−0.134	−1.021	2.739	1.932
	(1.15)	(2.14)*	(3.58)**	(5.53)**
Secondary education[a]	−0.905	−2.923	5.564	2.929
	(5.78)**	(5.70)**	(6.66)**	(8.19)**
Post-secondary education[a]	−1.714	−3.875	4.544	2.747
	(7.11)**	(6.50)**	(4.10)**	(6.99)**
Farm household	0.841	3.145	−2.588	−1.947
	(9.11)**	(11.22)**	(6.60)**	(10.41)**
Share of females in household	0.327	1.453	1.479	0.472
	(1.71)	(2.77)**	(1.68)	(1.62)
Ethnic indigenous	0.185	1.439	−0.551	−0.795
	(2.01)*	(5.16)**	(1.27)	(4.50)**
Electrified	−0.378	−0.694	4.098	3.442
	(4.35)**	(1.66)	(8.66)**	(9.92)**
(7 regional dummies included but not shown)				
Constant	−5.274	−10.269	−37.871	−29.073
	(2.87)**	(1.63)	(4.21)**	(7.94)**
Observations	3883	3438	3883	3438

Notes: Absolute value of t statistics in parentheses.
*Significant at 5%; **Significant at 1%.
[a] Education variables are based on highest education of any household member.