Fuel Choice in Developing Countries: Evidence from Bolivia*

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I. Introduction

This study examines household fuel choice and firewood use in the context of a developing country. I focus on Bolivia, where household use of firewood remains common.[1] I analyze data from the 1989 Bolivian Integrated Household Survey, collected nationally in urban areas of Bolivia, and I look at household fuel use from a broader perspective than previous studies on Bolivia, which addressed the use of forest resources in specific towns or provinces.[2] Building on previous studies of household fuel use in developing countries, I ask three questions relevant to the study of firewood choice and use in developing countries.[3] (1) Are fixed costs a barrier to switching to liquefied petroleum gas (LPG)? (2) What is the effect of income growth on firewood use? (3) Does female earned income influence household fuel choice?

To examine the first question, I compare fuel expenditures for households that use LPG with households that do not. If fuel expenditures for households without LPG use are higher than those with LPG use, controlling for other factors, this would suggest that some type of barrier to LPG use exists, such as the high fixed costs of LPG tanks and stoves.

The energy ladder describes the different combinations of fuels used at different stages of development, with movements up the ladder generally reflecting a cleaner fuel mix, given that economic development is associated with increased use of commercial rather than traditional fuels.[4] Therefore, economic development or, specifically, income growth, may alleviate the pressure on firewood resources. However, while increasing income may be correlated with fewer firewood users, for some households firewood may be a normal good; in these cases, an increase in income would be associated with an increase in firewood use. Depending on which effect is greater, overall firewood use could either increase or decrease with income growth. In this

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article, I use a Heckman selection approach to model both the choice of fuel type and firewood expenditures.[5]

The third research question asks what effect female earned income has on household fuel choice.[6] Based on previous empirical evidence showing that women have stronger preferences for spending income on food, female earned income is hypothesized to be positively related to fuel use.[7] Second, it is hypothesized that female earned income is associated with a lower likelihood of firewood use. This hypothesized relationship may result from women preferring cleaner fuels or time-saving technologies.

The article is organized as follows: first, I introduce the 1989 Bolivian Integrated Household Survey data and present some descriptive statistics. Second, I describe my empirical strategy for each research question. Third, I present evidence on fixed costs as a barrier to cleaner fuel use. Fourth, I discuss the results, demonstrating how income and female earned income are related to household fuel choices. I conclude by discussing the implications of my results for public policy.

II. Data Description

The 1989 Bolivian Integrated Household Survey (EIH) includes 7,624 households from 17 cities in Bolivia, from eight of the nine departmental capital cities and all other cities with a population of over 10,000.[8] This is the second survey in a series of annual surveys begun in 1988 in conjunction with the World Bank's project to promote Living Standard Measurement Study (LSMS) surveys in developing countries.[9] These surveys are unusual for developing countries because they include both income and expenditure information as well as other social and demographic indicators of living standards. In Bolivia, these are the only surveys to include both income and expenditure information for a wide geographic area. Although summary information from the EIH has been made available by the National Institute of Statistics, to date few economic studies have been published utilizing EIH data.[10] Here, the 1989 EIH is utilized rather than more recent rounds for two reasons. After 1989, information on the separate types of household fuel used was not collected, and the sample was limited to only capital cities and El Alto, excluding the smaller cities.

Among these households from urban Bolivia, the three most commonly used cooking fuels are LPG, kerosene, and firewood (95% of households use LPG, 12% use kerosene, and 6% use firewood). Although firewood use is more prevalent in rural areas, urban data are well suited for examining choice among fuels because of the greater availability of substitute commercial fuels, such as LPG.[11] Understanding how households behave in these urban areas, where alternate fuels are commercially available, may provide insight into how other households might behave if fuel choices were also made available to them, for example, in the rural areas of Bolivia or in other cities in developing countries where fuel options are currently more limited.

While the most common use of these household fuels is for cooking,

households also use them for artisan activity, lighting, home heating, and water heating. Most households use these fuels for family cooking (97%), while fewer than 10% use these fuels for other purposes. Bolivia has three very different geographic zones, which may be broadly categorized as the Andean region, the valley region, and the lowlands. Comparing the altitudes of capital cities gives a feeling for these differences. They range in altitude from 3,640 to 4,070 meters in the Andean region, from 1,866 to 2,790 meters in the valley region, and from 221 to 416 meters in the lowlands. Despite the high altitudes in the Andean region and accompanying colder temperatures during the winter months, household use of LPG, kerosene, or firewood for heating is rare. Among households in the cities in the 1989 EIH, 1% of households reported using the fuels for heating, ranging from 0% to 5% for the individual cities. Two of the other fuel uses reflect household use for family business: cooking for sale or artisan activity. While only 7% of households use fuels for cooking for sale and 1% for artisan activity, within these households, business fuel use may constitute a large percentage of total fuel use.

Tables 1 and 2 present sample means (population-weighted) of relevant variables from the 1989 EIH for all households, for all households in the valley region, and for firewood users in the valley region.[12] Sample means are presented separately for the valley region since I focus on firewood choice and expenditures in this region. In examining firewood use, I limit the sample to households from the valley region because kerosene purchases are limited by the government because of its use in cocaine manufacture.[13] While kerosene is still sold, its availability varies by region, so that kerosene use is practically nonexistent in Cochabamba and nearby cities in the valley region where controls may be stricter, given their proximity to coca-producing areas. This is seen in the 1989 EIH data, where only 1% of households in the valley region use kerosene, as compared with 12% when all regions are included. Since kerosene use is being discouraged, limiting the sample to these valley regions puts the focus here on the choice between firewood and LPG, which is more pertinent from a policy standpoint.

Sometimes firewood is purchased, whereas other times the household itself is the supplier, and household members gather firewood. According to data from the 1989 EIH, among households in the valley region that use firewood, 45% are firewood gatherers. Despite the drawbacks of using firewood as opposed to a cleaner and more convenient commercial fuel, households may have reasons to prefer cooking with firewood, for example, for flavor. Therefore, even if households cook with commercial fuels, they may continue to cook some meals with firewood. In fact, using various types of fuel is not uncommon. About 12% of households in the 1989 EIH sample use multiple fuels. The improved flavor of food cooked with firewood was mentioned frequently in my discussions in Bolivia. However, César Sevilla states that although the taste of food changes when households switch from wood to LPG, this has not generated a large resistance to switching.[14]

Per capita fuel expenditures are calculated from LPG, kerosene, and

TABLE 1

MEANS WITH STANDARD ERRORS IN PARENTHESES FOR FUEL EXPENDITURES, TOTAL EXPENDITURES, INCOME, AND TYPES OF FUEL USED, FROM 1989 BOLIVIAN INTEGRATED HOUSEHOLD SURVEY (Population Weighted)

Variable Name	All Households	All Households	Valley Households
Firewood use[a]	.06 (.003)	.07 (.01)	…
Kerosene use[a]	.12 (.004)	.01 (.002)	.05 (.02)
LPG use[a]	.95 (.003)	.98 (.003)	.81 (.03)
Per capita fuel expenditures (US$/month)	1.84 (.03)	1.87 (.04)	4.32 (.32)
Fuel expenditures as a proportion of total expenditures	.05 (.001)	.05 (.001)	.13 (.01)
Per capita firewood expenditures (US$/month)	…	…	3.18 (.29)
Per capita expenditures (US$/month)	49.51 (.99)	53.91 (1.64)	36.82 (1.79)
Household expenditures (US$/month)	208.40 (3.13)	220.58 (4.06)	181.82 (8.03)
Per capita income (US$/month)	59.54 (.95)	63.30 (1.65)	34.91 (2.91)
Proportion of female earned income	.25 (.004)	.27 (.01)	.29 (.02)
Female earned income + indicator[a]	.50 (.01)	.53 (.01)	.54 (.04)
Cooking for sale[a]	.07 (.003)	.08 (.01)	.15 (.03)
Artisan activity[a]	.01 (.001)	.01 (.002)	.01 (.01)
Lighting[a]	.03 (.0004)	.02 (.003)	.04 (.01)
Home heating[a]	.01 (.001)	.002 (.001)	0
Water heating[a]	.01 (.001)	.01 (.001)	.08 (.02)
Cooking for family[a]	.97 (.002)	.96 (.004)	.99 (.01)
N	6,892	2,074	195

[a] One if participates in activity, zero otherwise.

firewood price and quantity information from the 1989 EIH. Firewood expenditures for firewood collectors and other households with missing firewood prices were calculated by using imputed prices.[15] On average, households spend about US$1.84 per person on fuel monthly, and household fuel spending amounts to about 5% of total household expenditures (table 1).[16] Firewood users in the valley region spend, on average, a higher percentage (13%) of total expenditures on fuel.

Expenditures rather than current income are used in this study as the indicator of resources available to the household.[17] Expenditure data are sometimes argued to be more reliable than income data. Another reason to use expenditure data is that this study focuses on household-consumption decisions and not on the savings-versus-consumption decision. Expenditures may also be considered a proxy for permanent income; however, this interpretation is less valid if households are unable to smooth their consumption between periods. Per capita expenditures are used rather than total household expen-

TABLE 2

MEANS WITH STANDARD ERRORS IN PARENTHESES FOR DEMOGRAPHIC AND HOUSEHOLD CHARACTERISTICS FROM 1989 BOLIVIAN INTEGRATED HOUSEHOLD SURVEY
(Population Weighted)

Variables	All Households	Valley Households	Valley Firewood Users
Number of adults (13+)	3.17 (.02)	3.27 (.04)	3.68 (.12)
Household size	4.85 (.03)	4.89 (.05)	5.70 (.18)
Large household (5 or more)[a]	.53 (.01)	.54 (.01)	.68 (.03)
Older household head (40 or older)[a]	.55 (.01)	.59 (.01)	.69 (.03)
High-school degree, technical, or university education[a]	.42 (.01)	.47 (.01)	.34 (.03)
Older times education (interaction term)	.22 (.01)	.27 (.01)	.26 (.03)
Indigenous language spoken by head[a]	.41 (.01)	.46 (.01)	.74 (.03)
Uses electricity[a]	.94 (.003)	.90 (.01)	.79 (.03)
N	6,892	2,074	195

[a] One for households or household heads with attribute, zero otherwise.

ditures as a normalization to make them more comparable across different-sized households.[18]

Average per capita expenditures are about US$50 per month, as compared with average per capita income of US$60 per month (table 1). Per capita expenditures, household expenditures, and per capita income are all, on average, lower for valley firewood users than for valley households in general. This suggests that income growth may have an effect on firewood use. Looking at the female-earned-income variables, the percentage of household income attributable to female earners is 25% in the entire sample, somewhat higher in the valley region (27%), and even higher for firewood-using households in the valley region (29%). About 50% of households have female earned income, and this percentage is also somewhat higher in the valley region (53%) and even higher for firewood-using households in the valley region (54%). Examining some of the other demographic variables in table 2 demonstrates that firewood-using households in the valley region are larger than households overall. In addition, in firewood-using households in the valley region household heads tend to be older, a lower percentage have a high school degree or additional schooling, and a higher percentage speak an indigenous language than is true for household heads in general.

III. Empirical Strategy

Are Fixed Costs a Barrier to Switching to LPG?

If a household uses a more expensive fuel, even when the fixed costs are less than the present discounted value of expected savings from using the least

expensive fuel, then this may indicate credit-market constraints for purchasing durable goods.[19] I hypothesize that fixed costs are a barrier to using LPG for some households. I present evidence on the fixed costs required to use LPG as compared with kerosene or firewood. I also examine the available information on the relative prices of the fuels per unit of energy output. Then, I look at the difference between per capita fuel expenditures for households that use LPG and those that do not. Households that use LPG may also use firewood or kerosene, but the fact that they use at least some LPG means that they own the durable goods necessary for LPG use. If the prices of firewood and kerosene are higher than the price of LPG per unit of energy utilized, then fuel expenditures for exclusive kerosene and firewood users will be higher, given the same quantity of energy utilized. The same comparison is also examined in a regression framework, controlling for a variety of variables that may affect the quantity of fuel purchased.

The Impacts of Income and Female Earned Income on Household Fuel Choices

The second and third research questions ask how income growth and female earned income affect household fuel choices. First, the impact of both income growth and female earned income on overall fuel use is seen from the results of the per capita fuel expenditures regression described in the previous paragraph. Next, focusing on households from the valley region of Bolivia, I look at the effects of income and female earned income on firewood expenditures and on firewood choice. Since many households use no firewood, a Heckman selection model is estimated by maximum likelihood. This involves estimating both a firewood choice probit and a firewood expenditure regression, as explained below.

The estimation is based on the following model of firewood use. Whether a household chooses to use firewood can be represented by a binary variable, $Y = 1$, if firewood is used, and zero if not.[20] However, the underlying theory involves Y^*, which is the unobserved propensity to use firewood.

$$Y_i^* = \gamma' \mathbf{x_i} - \mu_i, \tag{1}$$

where Y_i^* is unobserved propensity to use firewood, and $\mathbf{x_i}$ is the vector of covariates.

To examine the impact of income on the probability of choosing firewood, the following probit model is estimated: the dependent variable is an indicator variable for firewood use that relates to the underlying Y^*, such that $Y = 1$ if $Y^* > 0$ and $Y = 0$ otherwise.

$$Pr(Y_i = 1|\mathbf{x}) = F(\gamma' \mathbf{x_i}), \tag{2}$$

where $Y = 1$ if a household uses firewood (and $Y^* > 0$).

This selection mechanism is incorporated in the regression model for firewood expenditures. The following regression model is observed if $Y = 1$:

$$z_i = \beta' \mathbf{w_i} + \epsilon_i, \tag{3}$$

where

$$(\mu_i, \epsilon_i) \text{ bivariate normal } [0, 0, 1, \sigma_\epsilon, \rho].$$

So when $Y = 1$:

$$E(z|Y = 1) = \beta' \mathbf{w_i} + \rho\sigma_\epsilon \lambda(\gamma' \mathbf{x}). \tag{4}$$

In the Heckman selection procedure, the estimated expenditure equation includes λ, which is obtained from the probit selection equation.

To examine the effect of income on firewood use, per capita household expenditures as a measure of available household resources is included as an explanatory variable.[21] Both linear and quadratic terms are included for per capita household expenditures. Overall, fuel is expected to be a normal good for households, while firewood is expected to be an inferior good, at least for some households. Therefore, an increase in household income is hypothesized to increase the quantity of fuel used (and thus the quantity of firewood, conditional on using firewood) but to decrease the probability of choosing to use firewood.

The third question concerns the effect of female earned income on household-fuel-choice and use decisions. Two different measures of women's earnings within the household are used. One is the proportion of female earned income to total household income, while the other is an indicator for female earned income in a household. Unfortunately, unearned income is not available on an individual basis in the 1989 EIH. A potential endogeneity issue arises when using earned income as a measure if women make their work decisions based on the need to purchase fuel. However, since fuel or firewood expenditures are generally a small percentage of household expenditures (on average 5%), it seems reasonable to argue that endogeneity is less of a problem when looking at fuel expenditures, as opposed to looking at expenditure items that are a larger proportion of the budget.[22]

Households with female earned income are expected to be less likely to use firewood. Relative to men, women may have stronger preferences for using a cleaner fuel than firewood, given their greater involvement in cooking. Female earned income may also indicate that women in the household have a greater opportunity cost of time, which is associated with choosing time-saving cooking technology. The mechanism linking female earned income to greater expression of female preferences may be that, with female earned income, women either have a greater say in household-consumption decisions or have increased access to nonpooled household income. In terms of fuel use, female earned income is expected to be positively related to fuel expenditures.

The other explanatory variables included in the probit equation are city indicator variables (Cochabamba, the largest city in the valley region, is the

omitted category), an indicator for large households (five or more members), an indicator for more highly educated household heads (a high school degree, technical or university education), an indicator for older household heads (40 years of age or older), an indicator for household heads who speak an indigenous language (either solely or in addition to Spanish), and an indicator for households that cook for sale.

The likelihood of choosing to use firewood is expected to be lower for those with higher education levels. The learning cost for switching to LPG use is likely to be lower for more highly educated persons, and they may be less likely to have the custom or habit of firewood use in their family. The preference for the flavor of food cooked with firewood may be associated with a stronger attachment to indigenous culture and traditional cooking. Therefore, those speaking an indigenous language are expected to be more likely to choose to use firewood. Firewood prices are not available; therefore, city indicator variables are included to control for geographic variation in relative fuel prices.[23] The interaction term between highly educated and older household heads is included since a recent education may have a different effect than a distant one.

In the per capita firewood expenditures regression, in addition to per capita expenditures and the female-earned-income indicator, the other explanatory variables include the number of adults (13 years of age or older) in a household, household size, city indicator variables, and an indicator for households that cook for sale. Some of the variables thought to affect expenditures on firewood are different from those included in the probit equation for firewood choice. Household head characteristics such as age, education, and whether an indigenous language is spoken are not expected to affect firewood expenditures directly and are excluded. Speaking an indigenous language is an indicator for stronger attachment to indigenous culture, which, as discussed previously, may be linked to cooking traditional dishes. However, firewood users in general are expected to cook traditional dishes, so, conditional on the use of firewood, indigenous culture would not be an important determinant of firewood expenditures.[24] Without these exclusion restrictions (variables expected to affect the probability of using firewood but not the amount spent on firewood), the identification of the parameters in the Heckman selection procedure would depend only on the functional form assumed. Also, instead of an indicator for large households, actual household size is included, as the relationship with per capita firewood expenditures is expected to be continuous. In addition, the number of adults is included, as children have different eating requirements than adults.

IV. Results: Are Fixed Costs a Barrier to Switching to LPG?

The durable goods needed to cook with LPG are at least one 10-kilogram tank and a stove. An empty tank must be returned when another tank filled with LPG is purchased. The cost of the tank alone is about US$25. The least

expensive LPG stove is essentially a one-burner unit, which cost less than US$10 in 1997. Stove prices in Bolivia in 1992 averaged about US$100.[25] In general, stoves and other appliances are not provided along with rental housing but must be supplied by the renters. The minimum fixed cost for durable goods needed to use LPG is therefore US$35, which is 16.8% of the average monthly household expenditure level of US$208 (for all households). However, for households not using LPG, it is 27.1% of the average monthly household expenditure level of US$129.[26] By contrast, kerosene cooking is predominantly done on relatively inexpensive small burners that hold one pot, and no special fuel containers are required.[27] The main fixed cost of a wood-burning stove is the labor cost for construction. Therefore, the fixed costs for the durable goods required to use LPG are higher than those for either kerosene or wood, assuming that the opportunity cost of time is low for those constructing the wood-burning stoves.

According to relative fuel price information from the Bolivian National Survey of Rural Energy Consumption, in rural areas of Bolivia, firewood is less expensive per unit of output energy than either kerosene or LPG.[28] The same price comparison cannot be done, for all the urban areas, with firewood prices from the 1989 EIH, as firewood prices are given in varying units, and the conversion factor to a standardized unit such as kilograms is not generally available. However, a comparison of relative fuel prices was possible for two urban areas in the valley region. In the department of Cochabamba, LPG and firewood prices per unit of energy are almost the same. In Tarija, LPG is approximately 0.12 bolivianos/10,000 kilocalories more expensive than firewood, a smaller price differential than in the rural areas.[29] This suggests that in urban areas firewood is more expensive relative to kerosene and LPG than in rural areas. This is not surprising since transportation costs would generally be higher for kerosene and LPG in rural areas than in urban areas, while firewood transportation costs would generally be higher in urban areas than rural areas. Comparing energy output prices for LPG and kerosene in the 1989 EIH cities, kerosene is always more expensive than LPG. These price comparisons reflect energy output but do not take into account varying efficiency of fuel use. Efficiency in firewood use may be particularly low. For example, one source estimated efficiency at 10% of energy output.[30] This implies that, if fuel efficiency were also taken into account, LPG might actually be less expensive per unit than either kerosene or firewood in urban areas.

Comparing total per capita fuel expenditures for LPG users with non-LPG users, LPG users on average spend US$1.22 per person less each month on fuel than non-LPG users (table 3). This suggests that households with no LPG use could reduce their per capita fuel expenditures by switching to LPG. Taken together with the previous information showing that the durable goods needed for LPG use are more expensive, one reason to explain why this switching does not always occur is that this cost of the durable goods serves as a barrier to using less expensive fuels. Purchasing an LPG tank and a one-

TABLE 3

PER CAPITA FUEL EXPENDITURES: COMPARING LPG USERS TO NONUSERS (Population-Weighted Means)

	Mean Per Capita Fuel Expenditures (US$/Month [SE])	Sample Size
LPG users	1.78 (.27)	N= 6,370
Non-LPG users	3.00 (.18)	N = 522
Difference	−1.22 (.18)	…

SOURCE.—1989 Bolivian Integrated Household Survey.
NOTE.—LPG = Liquefied petroleum gas.

burner stove would have a payback time period of slightly more than 2 years for a one-person household (using 1997 prices without discounting). This time period would be shorter for larger households.

However, other differences may exist that explain why households without LPG use spend US$1.22 per person per month more on fuel on average than households with LPG use. Therefore, the same comparison is examined in a regression framework. The results from this regression are presented in table 4.[31] In model 1, the parameter estimate on the indicator for LPG use shows that LPG users on average spend US$1.54 per month less on fuel than do non-LPG users with the same characteristics. This evidence is consistent with the hypothesis that fixed costs for durable goods may be a barrier to LPG use. Per capita fuel expenditures rather than total household fuel expenditures are examined to account for different household sizes having different fuel requirements.[32] However, household size is also included as an explanatory variable, as economies of scale in fuel use may exist. The estimated parameter on household size is negative, indicating the presence of economies of scale. In addition, the number of adults in the household is included as an explanatory variable, since fuel use may differ for adults. Having more adults in a household is associated with greater per capita fuel expenditures, but the effect is small.

If there are unobserved household characteristics that differ between LPG users and non-LPG users and also affect fuel expenditures for these two groups, then selection into these groups may be contributing to the difference in fuel expenditures. Both firewood users and indigenous peoples may be more traditional and cook traditional dishes that use more fuel, for example, dried corn. The indigenous language indicator variable is included to attempt to control for preference differences such as this.[33] The parameter estimate suggests that households in which an indigenous language is spoken by the head of household have greater per capita fuel expenditures. Fuel and food may be substitutes in some cases, for instance, if less expensive ingredients take longer to cook, or LPG users eat out more and cook less in the home. For this reason, had the data been available, it would have been useful to compare fuel costs per meal. However, by controlling for per capita expen-

TABLE 4

PER CAPITA FUEL EXPENDITURE REGRESSIONS, PARAMETER ESTIMATES WITH STANDARD ERRORS IN PARENTHESES (1989 EIH)

Variables[a] Dependent Variable: Per Capita Fuel Expenditures (US$)	Model 1	Model 2[b]	Model 3
LPG use indicator	−1.5428***	−1.3849***	−3.7082***
	(.1490)	(.1238)	(.2901)
Per capita expenditures (US$100)	1.8493***	.6338***	1.8669***
	(.0620)	(.0559)	(.0617)
Per capita expenditures (US$100) squared	−.0163***	−.0058***	−.0165***
	(.0006)	(.0005)	(.0006)
Number of adults (13+)	.0499*	.1159***	.0394
	(.0305)	(.0252)	(.0304)
Household size	−.2438***	−.3314***	−.5895***
	(.0226)	(.0187)	(.0465)
Proportion of female earned income	.1787*	−.0468	.1863*
	(.0995)	(.0824)	(.0990)
Indigenous language spoken by head	.3787***	.1849***	.3617***
	(.0797)	(.0654)	(.0793)
Cooking for sale	2.2349***	…	1.7561***
	(.1409)		(.4003)
Artisan activity	1.5568***	…	1.9765*
	(.2980)		(1.2108)
Lighting	1.2377***	1.0093***	1.3062***
	(.1733)	(.1518)	(.1725)
Home heating	.3401	.7382**	.3779
	(.3997)	(.3188)	(.3977)
Water heating	.8969***	.8735***	.9931***
	(.2167)	(.1794)	(.2166)
Cooking for family	2.0902***	.9429***	2.1185***
	(.2225)	(.3458)	(.2214)
Uses electricity	−.0843	−.0379	−.0279
	(.1515)	(.1273)	(.1509)
LPG use multiplied by household size (interaction term)	…	…	.3955***
			(.0463)
LPG use multiplied by artisan activity (interaction term)	…	…	−.5268
			(1.2486)
LPG use multiplied by cooking for sale (interaction term)	…	…	.5484
			(.4172)
Constant	.8705***	2.8504***	2.7196***
	(.3163)	(.4107)	(.3802)
R^2	.2311	.1676	.2396
Standard error of the regression	2.6923	2.1184	2.678

NOTE.—Conversion to US$ at November 1989 exchange rate of 2.7 bolivianos/US$; N = 6,892. LPG = liquefied petroleum gas.

[a] City indicator variables also included in estimation.

[b] Excluding households with business use of fuel (592 households).

* Significant at 10% level.

** Significant at 5% level.

*** Significant at 1% level.

diture levels, differences like these may be partially captured to the extent that they relate to differences in income levels. The parameter estimates on the linear and quadratic terms for per capita expenditures suggest that fuel expenditures rise with per capita expenditures, but at a declining rate (discussed further in Sec. V). As the proportion of female earned income in a household increases, per capita expenditures increase (discussed later in Sec. VI). Selection bias may also be less of a problem given the way that the groups are defined. As long as they also use LPG, households that use kerosene or firewood are included in the LPG-user group, which makes the control group more similar to the kerosene and firewood-using group, except for having LPG use as well.

Indicator variables for various uses of the three fuels are included in the regression. Those households that have business fuel uses, such as cooking for sale and artisan activities, have greater per capita fuel expenditures than those that do not, and the parameter estimates are statistically different from zero. For households that use these fuels for lighting or water heating, per capita fuel expenditures are also greater than for those households that do not, although the magnitudes of the differences are smaller than for the business uses. Most of the households (97%) use at least one of these fuels in family cooking, and, as might be expected, their fuel expenditures are substantially higher than those for families that do not use these fuels for family cooking. Households that use these fuels for home heating are also estimated to spend more per capita on fuel than those that do not; however, the parameter estimate is not significantly different from zero and is small in magnitude. Households with electricity are estimated to have lower per capita fuel expenditures, as might be expected, to the extent that these fuels are substitutes for electricity in those households with no electricity; however, the parameter estimate is also small in magnitude and not statistically different from zero.

To make sure that the household use of fuel for artisan purposes or cooking for sale is not driving the results, model 2 is estimated, excluding households with either of these business uses (592 households). The LPG users are estimated to use US$1.38 less fuel per capita than non-LPG users, an amount only slightly smaller in magnitude than the parameter estimate in model 1.[34] Another approach is attempted in model 3, where interaction terms with the LPG-use indicator are included for artisan use, cooking for sale, and household size. The interaction term with household size is included further to capture economies of scale for which the expenditure difference on the margin, given another household member, may be different from the average. The result that LPG users spend less on fuel than non-LPG users does not change. In fact, the estimated difference is now US$3.71, which is greater than it is in model 1.

Both the simple comparison of mean per capita fuel expenditures and the regression results show that non-LPG users spend more on fuel than do LPG users. In combination with the evidence presented previously, that even the least expensive purchase of durable goods for LPG use would be about

27% of the average monthly household spending in households with no LPG use, this supports the hypothesis that these fixed costs may be a barrier to switching to LPG.

However, while this evidence is consistent with fixed costs as a barrier to LPG use, it is also consistent with other explanations.[35] For example, perhaps the implicit costs of purchasing LPG are higher for those who do not purchase LPG. Implicit costs for households may vary because of the different ways in which LPG is purchased and the distance from the point of purchase. In urban areas, LPG is most frequently purchased from trucks, although in the valley regions, store and agency purchases are also common.[36] In the past, shortages of LPG have occurred, causing a break in the supply, but this is fairly rare now.[37] In addition, while this analysis attempts to control for a variety of factors influencing fuel choice, it is possible that other noneconomic factors, such as family tradition, are not completely captured and could be affecting fuel choices.

V. Results: Does Income Growth Lead to Decreased Firewood Use?

The Impact of Income on Fuel Use

The impact of income on overall fuel use is seen in the regression results in table 4. Per capita fuel expenditures increase with per capita household expenditures, although at a decreasing rate, as the quadratic term is negative.[38] The effect turns negative at very high expenditure levels; for example, the turning point is at per capita expenditures of US$5,673 per month in model 1. Using the results from model 1, an increase of US$1 in per capita expenditures implies an increase of about 2 cents in per capita fuel expenditures when evaluated at the average per capita expenditure level of US$49.51 per month. This implies a relatively inelastic expenditure elasticity of 0.49. Since the dependent variable is fuel expenditures (or, later, firewood expenditures), one concern might be potential endogeneity, that is, household expenditures rise because of an increase in fuel expenditures. However, as shown in table 1, fuel expenditures are generally a small share of total expenditures (5% on average), so this is less likely to be a problem.

The Impact of Income on Firewood Choice

While income is positively related to overall fuel expenditures, results from the Heckman selection procedure demonstrate the impact of income on firewood choice and firewood expenditures. The results from the probit models of firewood choice are in table 5. As seen in model A, per capita expenditures are negatively related to the probability of choosing firewood, although, since the quadratic term is positive, the magnitude of the negative impact is decreasing as per capita expenditures increase. The turning point at which the positive effect from the quadratic term equals the negative effect from the linear term is US$975 per capita, and the ninety-ninth percentile for per capita expenditures in the sample is US$229 per capita. Since this turning point is so high and the parameter estimate on the quadratic term is not statistically

TABLE 5

FIREWOOD CHOICE: PROBIT RESULTS FOR VALLEY HOUSEHOLDS, PARAMETER ESTIMATES WITH STANDARD ERRORS IN PARENTHESES (1989 EIH)

Variable Names Dependent Variable: Firewood = 1	Model A	Model B	Model C
Per capita expenditures (US$100)	−.5130*** (.1927)	−.5482*** (.2104)	−.5059*** (.1926)
Per capita expenditures (US$100) squared	.0263 (.0195)	.0282 (.0205)	.0259 (.0196)
Older household head (40 or older)	.0084 (.1144)	.0469 (.1256)	−.0012 (.1150)
High-school degree, technical, or university education	−.4575*** (.1644)	−.4234*** (.1763)	−.4640*** (.1650)
Older multiplied by education (interaction term)	.4073** (.1995)	.3826* (.2149)	.4147** (.2001)
Large household (5 or more)	.1879** (.0977)	.2111** (.1065)	.1939** (.0981)
Indigenous language spoken by head	.5803*** (.1153)	.6669*** (.1251)	.5847*** (.1159)
Female earned income indicator	−.1428 (.0905)	−.1614* (.0965)	−.1749* (.0952)
Cooking for sale	.5046*** (.1424)	…	.2501 (.2778)
Female earned income indicator multiplied by cooking for sale indicator (interaction term)	…	…	.3558 (.3240)
Sucre[a]	−.4547*** (.1621)	−.4499* (.1731)	−.4495*** (.1624)
Tarija[a]	.6418*** (.1308)	.6888*** (.1432)	.6420*** (.1312)
Quillacollo[a]	.6859*** (.1312)	.6784*** (.1393)	.6866*** (.1313)
Punata[a]	1.4797*** (.1637)	1.5300*** (.1784)	1.4941*** (.1643)
Constant	−1.8244*** (.1855)	−1.9115*** (.2015)	−1.8139*** (.1857)
Log likelihood	−1,036.27	−874.49	−1,034.82

NOTE.—N = 2,074 (174 households excluded from model B); EIH = Bolivian Integrated Household Survey.

[a] City indicator variables; omitted city is Cochabamba.

* Significant at 10% level.

** Significant at 5% level.

*** Significant at 1% level.

significant, for all relevant purposes the estimated relationship shows that as spending power increases a household is less likely to use firewood.[39]

Households where the head has a high school degree or a technical or university education are less likely to use firewood, and this education effect is stronger for younger household heads. This may reflect a lower learning cost for switching to a commercial fuel for more highly educated households. Households where the household head speaks an indigenous language are more likely to use firewood, perhaps because of the preference for the flavor of traditional meals cooked with firewood, as previously discussed. Larger households and households that cook for sale are also more likely to use firewood. Households with older household heads are less likely to use firewood, although this parameter estimate is not statistically different from zero.

The parameter estimates on the city indicator variables are all statistically significant in the choice of firewood. The city indicator variables are expected to reflect differences in relative fuel prices among the cities, since prices were not available for firewood in standardized units.[40] Households in all cities except Sucre are more likely to choose firewood than are households in Cochabamba (the omitted category). The ranked ordering suggested by the parameter estimates implies that the price of firewood relative to other fuels may be highest in Sucre and lowest in Punata. For the two cities of Tarija and Cochabamba, this is consistent with the relative price comparison given earlier, showing that firewood was less expensive relative to LPG in Tarija than in Cochabamba. While it would be interesting to compare these results to data on the relative availability of firewood or the rate of deforestation in these areas, to my knowledge information by city does not exist.[41]

Since some households also use fuel for home businesses, cooking for sale is included as a control variable. However, to check that households with the business purposes of either artisan activities or cooking for sale are not driving the results, model B estimates omit these 174 households. Compared with that of model A, the results are quite similar. As per capita expenditure levels increase, the probability of using firewood declines, although at a decreasing rate because of the positive quadratic term. The impact of female earned income on firewood choice will be discussed in Section VI, along with the specifications estimated in model C, which primarily relate to that issue. However, the parameter estimate on per capita expenditures in model C is very similar to that in model A.[42]

The Impact of Income on Firewood Expenditures

The estimation results for the firewood expenditure regressions are in table 6.[43] Looking at model A, per capita expenditures are positively associated with per capita firewood expenditures, and the estimated parameter is statistically different from zero. The quadratic term is negative but not statistically different from zero. Using the point estimates from model A, evaluated at the mean per capita expenditure level for firewood users of US$36.82 per month, an increase in per capita expenditures of US$1 would result in about an 8-cent increase in

TABLE 6

PER CAPITA FIREWOOD EXPENDITURES REGRESSION RESULTS FROM HECKMAN SELECTION MODEL: VALLEY HOUSEHOLDS, PARAMETER ESTIMATES WITH STANDARD ERRORS IN PARENTHESES (1989 EIH)

Variable Names Dependent Variable: Per Capita Firewood Expenditures (US$)	Model A	Model B	Model C
Per capita expenditures (US$100)	9.9525*** (3.9441)	8.8457** (3.9371)	10.0089*** (3.9251)
Per capita or household expenditures (US$100) squared	−3.2168 (2.8006)	−3.8250 (2.7975)	−3.3582 (2.7903)
Number of adults (13+)	−.0976 (.2697)	.0742 (.2721)	−.0842 (.2685)
Household size	−.2337 (.2117)	−.3601* (.2121)	−.2431 (.2108)
Female earned income indicator	.0353 (.6087)	.0890 (.6140)	.3084 (.6388)
Cooking for sale	2.0451** (.9286)	…	3.9381*** (1.5866)
Female earned income indicator multiplied by cooking for sale indicator (interaction term)	…	…	−2.7101 (1.9084)
Sucre[a]	1.1748 (1.5172)	1.3357 (1.5075)	1.1104 (1.5112)
Tarija[a]	1.3494 (.9748)	1.1880 (1.0136)	1.3953 (.9725)
Quillacollo[a]	.1821 (1.1327)	.6516 (1.1274)	.2020 (1.1385)
Punata[a]	1.4424 (1.4768)	1.5453 (1.4673)	1.4323 (1.5068)
Constant	2.8005 (2.4519)	3.0627 (2.3412)	2.5104 (2.4827)
Lambda	−1.1809 (.9437)	−1.0734 (.8918)	−1.0678 (.9700)

NOTE.—N = 195 (29 households excluded from model B); EIH = Bolivian Integrated Household Survey.

[a] City indicator variables; omitted city is Cochabamba.

* Significant at 10% level.

** Significant at 5% level.

*** Significant at 1% level.

per capita firewood expenditures. Therefore, increased spending power, conditional on using firewood, tends to increase firewood use. The implied expenditure elasticity is 0.88, which is relatively inelastic.

Household size and the number of adults are both negatively related to per capita firewood expenditures, although the estimated parameters are not significantly different from zero. The negative impact of household size may reflect economies of scale in fuel use. The negative parameter estimate on the number of adults is somewhat surprising, as adults would be expected to eat more than children.

Cooking for sale is positively related to per capita firewood expenditures, of substantial magnitude, and statistically different from zero. The parameter estimates for the city indicator variables are positive, indicating higher firewood expenditures in these cities than in the omitted city of Cochabamba. However, unlike in the probit equations, these parameter estimates are not statistically different from zero, suggesting that they do not significantly explain differences in firewood expenditures.

The specification in model B tests the sensitivity of the results to the omission of households with business fuel use. When households that either have artisan activities or that cook for sale are omitted, an extra US$1 in the per capita expenditure level results in a 6-cent increase in per capita fuel expenditures, slightly less than the 8-cent increase estimated from model A. As in model A, the effect of household size is negative. By contrast, in model B, the parameter estimate on the number of adults is positive, although not statistically significant. In the fuel expenditure regressions seen previously in table 4, the number of adults was also positively related to fuel expenditures. This suggests that the estimated negative relationship shown in model A either has to do with the type of fuel or is related to business firewood use.

The positive relationship between per capita expenditures and firewood expenditures is found consistently in the estimated alternative specifications. As seen in table 6, the estimated linear effect of expenditures on firewood expenditures is also positive and statistically significant in models B and C.[44] The parameter estimates for the city indicator variables are not significant in any of the specifications.[45] Model C is discussed in more detail in Section VI, as are the parameter estimates on the female-earned-income indicators.

The Overall Impact of Income on Firewood Use

The probit-choice and the firewood-expenditure-equation results imply two opposing effects of income on firewood use. To look at the combined effect of these two margins, I use the Heckman selection results from model A to examine the change in predicted firewood expenditures from an increase of US$5 in per capita expenditures.[46] This increase in spending power affects both the probability that the household uses firewood (and, thus, the number of firewood users) and firewood expenditures, if firewood is chosen. The probit equation predicts a decline in the probability of firewood use of 0.0032 in the overall sample. This is equivalent to seven of the 192 firewood-using

households eliminating firewood use.[47] All but three households in the sample have a lower predicted probability of firewood use after the US$5 per capita expenditure increase.[48] From the firewood-expenditure equation, all but one household is predicted to increase spending on firewood after the expenditure increase. The average per capita increase in firewood expenditures is 25 cents, or an average increase per household of US$1.53. Combining these two margins results in an overall predicted increase in firewood expenditures of 10% of actual firewood expenditures.[49]

The results of Section V show that the impact of an increase in per capita expenditure levels has two opposing effects on household firewood use. The increase in spending power results in some households eliminating firewood use, while those households that continue to use firewood increase their firewood use. This suggests that small changes in income growth alone will not reduce overall firewood use by households.

VI. Results: Is Female Earned Income Important in Household Fuel Choice?

Female Earned Income and Fuel Expenditures

Looking at the relationship between female earned income and overall fuel expenditures in the regression with per capita fuel expenditures in table 4, model 1, as the proportion of female earned income increases, per capita fuel expenditures increase (this parameter estimate is statistically different from zero at the 10% significance level). This result is similar to that found in the Ivory Coast by J. Hoddinott and L. Haddad, where an increase in the wife's share of income is associated with an increased budget share of fuel.[50] Here, a change from zero female earned income to all female earned income is associated with an increase in spending on fuel per capita of 18 cents, a 10% increase if evaluated at the mean per capita fuel expenditures of US$1.84 per month. This estimated relationship is similar in model 3, which includes interaction terms between LPG use and household size, artisan activity, and cooking for sale. However, in model 2, when households with artisan activities or cooking for sale are omitted, the parameter estimate is negative, although not statistically significant. This suggests that the positive relationship between fuel use and the proportion of female earned income is influenced by the relationship between female earned income and cooking for sale.[51] While these results suggest that female earned income may be important in the fuel-expenditure decision, they do not shed direct light on the effect of female earned income on firewood use. To explore this effect, the results from the Heckman selection model are examined.

Female Earned Income and Firewood Use

In model A, in the probit models of firewood choice in table 5, the parameter estimate on the female-earned-income indicator is negative, although only statistically different from zero at the 11.5% significance level.[52] If cooking for sale is associated with a greater likelihood of both firewood use and having

female earned income, then this relationship may be obscuring any direct relationship between female earned income and the likelihood of using firewood.[53] To address this issue, model B omits households with business uses of fuel, including cooking for sale. The parameter estimate on the female-earned-income indicator is again negative and is statistically different from zero at the 10% significance level. In model C, this relationship between female earned income and cooking for sale is controlled for by including an interaction term between these two variables. Again, households with female earned income are less likely to use firewood, and the parameter estimate is significant at the 10% significance level. This suggests that households with female earned income are less likely to use firewood, and the relationship is strongest for households with no business use of fuel or no cooking for sale. In the firewood-expenditure equation for valley households in table 6, the parameter estimate on female earned income is not statistically different from zero in any of the models. Thus, available evidence suggests that female earned income does not affect the level of per capita firewood expenditures, conditional on a household choosing to use firewood.

The combined evidence suggests that female earned income may matter in the household-fuel-choice-decision-making process. The association of female earned income with a lower probability of firewood use may be caused by greater opportunity costs of time for women who work for monetary compensation. Cooking with firewood is more time-consuming than cooking with LPG, and women working for monetary compensation may have less time for cooking. This cannot be distinguished from the explanation that women may have stronger preferences than men for cooking with a cleaner fuel. Whichever underlying reason explains the relationship, the influence of female earned income may affect the implementation of different fuel-use policies.

VII. Summary and Conclusions

This article addresses three economic questions relating to household fuel use in Bolivia. In addition to adding to our understanding of household behavior in developing countries, the presented results have specific policy implications for development projects aimed at reducing firewood use in those countries.

I compared per capita fuel expenditures for LPG users with those of non-LPG users and found that, all else being equal, LPG users spend less on fuel. This is evidence that a barrier to LPG use may exist, such as high fixed costs of purchasing durable goods combined with credit constraints. This implies that development projects encouraging households to switch to a cleaner fuel need to be aware of potential fixed-cost problems, even if the alternate fuel is attractive from a per unit cost perspective. This finding suggests that policies designed to encourage households to switch to a cleaner fuel might target either subsidies or credit access for purchase of the necessary durable goods. If cleaner fuels are actually less expensive per unit than firewood, a policy of increased access to these durable goods could help families lower their

overall fuel costs and reduce the problems associated with firewood use at the same time. Fixed costs of durable goods may also still be a barrier in locations where the per unit cost of the cleaner fuel is somewhat higher than the per unit firewood cost, as households may be willing to pay a higher per unit price in order to use a cleaner and more convenient fuel.

The importance of fixed costs in a household's fuel choice suggests that this may also be an issue in other areas of household consumption. For example, with other types of technology transfers such as improved woodstoves, fixed costs may also be a barrier to adoption if the costs are significantly higher than for the traditional stoves. Other examples, where fixed costs may be important for development projects, may include the expansion of access to potable water, electricity, and sewage disposal. Similar to the fuel-choice issue, poorer households may find themselves paying higher per unit prices (or having inferior or no access to services) but being unable to afford the initial cost of access to the distribution system.

I also found that as income increases, the probability of using firewood decreases, which is consistent with the idea of an energy ladder, where households switch to cleaner fuels as income increases. However, the results also show, at least for a marginal increase in income, that increased firewood use among those who continue to use firewood is likely to outweigh the reduction in firewood use from households that stop using firewood. This result highlights the importance of considering the effect of income on both the choice of firewood as a fuel and the amount of firewood used. This is not the same as concluding that economic development is not associated with movements up the energy ladder; however, it suggests that small changes in income, holding other types of societal changes constant, might result in increased fuel use, including increased firewood use. Given the nature of the available cross-sectional data, nothing definite can be concluded about the effect of larger-than-marginal changes in income. The results illustrate that any impact of income growth on firewood use is likely to come from changes in fuel-use patterns among current firewood users. Economic development that targets this population could have the potential overall impact of reducing firewood use, if the number of households that stop using firewood outweighs the impact of increased firewood use by those who continue using firewood.

Female earned income within the household was found to be important for some aspects of household-fuel-use decisions. This reinforces a growing awareness that intrahousehold interactions may be important in understanding household-consumption decisions. One finding of this work is that, as the proportion of female earned income increases, per capita fuel expenditures increase as well. This result seems consistent with previous studies that found a positive association between women's income and spending on food. However, among valley households, while female earned income is not statistically significant in explaining firewood expenditures, households with female earned income are less likely to use firewood, particularly among households with no fuel use for business purposes. This suggests that generating more

economic opportunities for women to earn income, other than cooking for sale, may be associated with reduced firewood use. Another implication is that in designing policies for reducing the negative effects of firewood use, whether this includes incentives for households to switch to cleaner fuels or to use more efficient wood-burning stoves, the role of women in the household-fuel-choice decision-making process should not be ignored. The evidence on the effect of female earned income suggests that learning more about how the intrahousehold decision-making process works regarding household fuel use may help us to understand the role that economic development could play in reducing firewood use.

In conclusion, my results suggest various policy options for the reduced use of firewood. The environmental problems of deforestation and indoor air pollution stemming from household firewood use appear unlikely to disappear simply through small increases in income. Attention should be paid to the possibilities of increasing use of cleaner, alternate fuels by reducing the fixed costs of the needed durable goods. In addition, increased economic opportunities for women may have the added benefit of reducing demand for firewood.

Notes

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1. In 1985, according to PPD/PNUD-LIDEMA-CIMCA, *Evaluación de cocinas mejoradas en el medio rural de Bolivia* (Evaluation of improved stoves in rural Bolivia) (La Paz: Editorial Acción, 1996), 45% of the total Bolivian energy demand was supplied by biomass fuels, of which 67% was wood.

2. See Rhinda Elizabeth Calla Gutierrez, "Manejo de recursos forestales desde la perspectiva de genero, en tres comunidades rurales del Canton Vacas, Provincia Arani Caso: Pedregal, Sacha-Sacha y Rosas Pampa" (Gender perspectives on the management of forest resources in three rural communities in the canton of Vacas in the province of Arani: Pedregal, Sacha-Sacha and Rosas Pampa) (Undergraduate thesis, Universidad Mayor de San Simon, 1995); Centro de Formación e Investigación Interdisciplinaria (CEFOIN), *Producción agropecuaria y vida rural en las provincias Mizque y Campero* (*estudio y seguimiento socioeconómico*) (Agricultural production and rural life in the provinces of Misque and Campero, a socioeconomic study and verification) (Cochabamba, Bolivia: Universidad Mayor de San Simon, Programa de Desarrollo Alternativo Regional, 1990).

3. Examples of previous studies on fuel use in developing countries include Gregory S. Amacher, William F. Hyde, and Keshav R. Kanel, "Household Fuelwood Demand and Supply in Nepal's Tarai and Mid-Hills: Choice between Cash Outlays and Labor Opportunity," *World Development* 24 (1996): 1725–36; Nadeem A. Burney and Naeem Akhtar, "Fuel Demand Elasticities in Pakistan: An Analysis of Households' Expenditure on Fuels Using Micro Data," *Pakistan Development Review* 29 (1990):

155–74; Asmerom Kidane, "Demand for Energy in Rural and Urban Centres of Ethiopia: An Econometric Analysis," *Energy Economics* 13 (1991): 130–34; M. Macauley, M. Naimuddin, P. D. Agarwal, and J. Dunkerley, "Fuelwood Use in Urban Areas: A Case Study of Raipur, India," *Energy Journal* 10 (1989): 157–80; Edward I. Onyebuchi, "Alternate Energy Strategies for the Developing World's Domestic Use: A Case Study of Nigerian Households' Fuel Use Patterns and Preferences," *Energy Journal* 10 (1989): 121–38; Mark M. Pitt, "Equity, Externalities and Energy Subsidies: The Case of Kerosene in Indonesia," *Journal of Development Economics* 17 (1985): 201–17.

4. See Kirk R. Smith, "Air Pollution: Assessing Total Exposure in Developing Countries," *Environment* 30 (December 1988): 16–35, for more on the description of the energy ladder. Commercial fuels (sometimes called modern fuels) include natural gas, LPG, kerosene, and electricity. Traditional fuels include firewood, agricultural residues, and dung. Firewood is classified as a traditional fuel, even though it is frequently sold commercially as well.

5. Pitt estimates Tobit equations for each fuel type in his examination of the kerosene subsidy in rural and urban Indonesia. While this accounts for the problem of households with zero expenditures for a particular fuel, the disadvantage of the Tobit model is that if a variable increases the probability of selecting into the group (e.g., firewood users), it also increases the conditional mean of the variable of interest (e.g., firewood expenditures; see also William H. Greene, *Econometric Analysis*, 2d ed. [New York: Macmillan, 1993]).

6. A related literature examines gender influences on fuel use and focuses on women's landholdings or women's collection time in rural areas where female earned income would not be as common. For example, see Priscilla A. Cooke, "Intrahousehold Labor Allocation Responses to Environmental Good Scarcity: A Case Study from the Hills of Nepal," *Economic Development and Cultural Change* 46, no. 4 (1998): 807–30; Sara J. Scherr, "Economic Factors in Farmer Adoption of Agroforestry: Patterns Observed in Western Kenya," *World Development* 23 (1995): 787–804.

7. For example, work by John Hoddinott and Lawrence Haddad ("Does Female Income Share Influence Household Expenditures? Evidence from Côte d'Ivoire," *Oxford Bulletin of Economics and Statistics* 57 [1995]: 77–96) finds, using data from the Ivory Coast, that an increase in the wife's share of income is associated with an increased budget share of food and a reduced share of alcohol and cigarettes. They also find a positive relationship between the wife's share of income and the budget share of fuel, although the parameter estimate is not statistically different from zero.

8. When not specifically cited, Sec. II draws on personal observation and my discussions with various Bolivian economists and engineers. The sample used in this article is 6,892 households, after eliminating households with missing or unreliable data, as well as 159 households that do not use any of the three fuels of interest. When valley households are the focus, the sample size is 2,081. When age and education of the household head are both included, the sample size falls to 2,074 because of additional missing data. More details on the data set and variable definitions may be found in Debra K. Israel, "Essays on Energy, Equity, and the Environment in Developing Countries" (Ph.D. diss., University of Wisconsin—Madison, 1999).

9. Margaret E. Grosh and Paul Glewwe, "A Guide to Living Standards Measurement Study Surveys and Their Data Sets," Living Standards Measurement Study Working Paper no. 120 (World Bank, Washington, D.C., 1995).

10. Summarized data from the 1989 EIH are available in Instituto Nacional de Estadística, *Encuesta integrada de hogares* (Integrated household survey) (La Paz: Republica de Bolivia, 1989). Masako Ii, "Willingness to Pay for Medical Care: Evidence from Urban Areas in Bolivia" (Ph.D. diss., University of Wisconsin—Madison, 1993), estimated the willingness to pay for medical care with 1990 EIH data. The 1989 EIH data were used in investigating returns to schooling for women and different ethnic groups (George Psacharopoulos, "Ethnicity, Education, and Earnings in Bolivia and

Guatemala," *Comparative Education Review* 37 [1993]: 9–20); Katherine MacKinnon Scott, "Women in the Labor Force in Bolivia: Participation and Earnings," in *Women's Employment and Pay in Latin America,* ed. George Psacharopoulous and Zafiris Tzannatos (Washington, D.C.: World Bank, 1992), pp. 21–38.

11. According to Instituto Nacional de Estadística, *Censo nacional de poblacion y vivienda 1992: Resultados finales* (1992 National population and housing census: Final results) (La Paz: Ministerio de Planeamiento y Coordinación, 1993), LPG is the predominant fuel in urban areas (81% use), while firewood is the most frequently used in rural areas (76% use).

12. Expenditures and income are in US$, converted from bolivianos at the November 1989 exchange rate of 2.7 bolivianos/US$.

13. The regulation exists at the point of sale; if retail outlets sell large amounts of kerosene, they are inspected (Mario Macedo, Yacimientos Petrolíferos Fiscales Bolivianos, personal communication, July 1996).

14. César Sevilla, "Valoración de la Propuesta 'Leña por GLP' en el Valle Central de Tarija" (Evaluation of the proposal "LPG for firewood" in the central valley of Tarija) (unpublished report, Deutsche Gesellschaft für technische Zusammenarbeit [GTZ], Bolivia, 1993).

15. When firewood prices were missing for collectors and other households with positive firewood use, the price for the household was imputed using the mean for the city, the region, or the national average—in that order of preference, depending on availability for each given firewood unit of measure.

16. To have an idea of the quantities of fuel that households use, per capita purchases of kerosene averaged 7.3 liters per month (equivalent to 64,800 kilocalories of output energy), and per capita purchases of LPG averaged 5.3 kilograms per month (62,600 kilocalories).

17. Total expenditures are defined to exclude expenditures on durable goods such as houses, cars, furniture, electrical appliances and kitchenware, and miscellaneous expenses such as real estate taxes, house improvements, insurance, and interest payments. For the durable goods items, it is unclear, on a theoretical basis, that the entire purchase amount should be included in an expenditure measure that is otherwise a measure of flows rather than stocks of goods. In addition, all of these expenditures were reported on an annual basis, and the amount of missing data is substantial.

18. While it would be interesting to look at the fuel cost per meal, this was not available using these data.

19. Households in the United States, particularly low-income ones, have been found to have high implied discount rates in the trade-off between purchase costs for energy-efficient appliances and the future savings from lower-energy utilization costs. This suggests that U.S. households do not always choose to use energy-efficient appliances. The high implied discount rates may reflect greater liquidity constraints for low-income consumers. See, e.g., Jerry A. Hausman ("Individual Discount Rates and the Purchases and Utilization of Energy-Using Durables," *Bell Journal of Economics* 10 [1979]: 33–54) on the demand for air conditioners. In a developing country, however, credit market constraints may be more of a factor than they are in the United States.

20. This discussion on the Heckman selection model is based on Greene (n. 5 above).

21. As in the fuel expenditure regressions, per capita expenditures are used rather than total household expenditures as a normalization to make them more comparable across different-sized households.

22. Hoddinott and Haddad (n. 7 above) use the spouse's share of income as their measure and try to correct for possible endogeneity using two-stage least squares.

23. One limitation of this is that relative fuel price variation within a city is not accounted for. However, even if firewood prices were available, it would be difficult

to account for the relative price per unit of usable energy (taking into account the different energy efficiency of stove types).

24. In support of this, for valley households, mean per capita firewood expenditures for households in which the head speaks an indigenous language is US$3.20, which is similar to that for other firewood-using households (US$3.12).

25. The LPG distributors cannot provide special tanks to ensure future customer loyalty as the LPG tanks are completely interchangeable. A tank price of $25 was obtained by author observation, July 1997, Cochabamba, Bolivia. Similarly, the price was US$28 in La Paz and El Alto in 1992, according to unpublished National Institute of Statistics data (INE, La Paz). The one-burner stove price was obtained by author observation, July 1997, Cochabamba, Bolivia, whereas the average 1992 stove price is from unpublished National Institute of Statistics data (INE, La Paz).

26. Average expenditure levels calculated from 1989 EIH data.

27. From the author's observation, in July 1997, a small one-burner kerosene stove cost less than US$10 in Cochabamba.

28. Instituto Nacional de Estadística, *Encuesta nacional de consumos de energía en el area rural de Bolivia: Sector doméstico rural* (National survey of energy consumption in rural Bolivia: Rural household sector) (La Paz: Republica de Bolivia, 1996).

29. The price comparison is based on the following conversion assumptions for firewood: for Cochabamba, 1 caballete = 20 kilograms (Nelly Tapia Balderrama, "Problemas de la tecnologia apropiada y la unidad familiar campesina [caso biodigestor]" [Undergraduate thesis, Universidad Mayor de San Simon, 1992]); for Tarija, 1 carga = 22.5 kilograms (Sevilla, "Valoración de la Propuesta 'Leña por GLP' en el Valle Central de Tarija" [n. 14 above]). The conversions for kilograms/kilocalories are taken from Instituto Nacional de Estadística, *Encuesta nacional de consumos de energía en el area rural de Bolivia*.

30. César Sevilla, "Políticas en energía y medio ambiente" (Energy and environmental policies) (unpublished report, La Paz, 1993).

31. In addition to the explanatory variables presented in table 1, city indicator variables for the 16 cities of Sucre, Cochabamba, Oruro, Potosi, Tarija, Santa Cruz, Trinidad, El Alto, Quillacollo, Punata, Llallagua, Huanuni, Tupiza, Camiri, Montero, and Riberalta were included in the estimation, with La Paz as the omitted category.

32. Similar results are obtained when model 1 is estimated using total household fuel expenditures and total household expenditures instead of per capita expenditures (including both linear and quadratic terms for household size as explanatory variables). The estimated parameter on the LPG use indicator is -3.89 and statistically different from zero at the 1% significance level.

33. It is difficult to control entirely for these potential differences since nonindigenous firewood users are also expected to cook traditional dishes. If an indicator variable for wood use is included in model 1, the parameter estimate is positive (2.61) and statistically significant. The LPG users are still estimated to spend less on fuel than non-LPG users, although the magnitude of the difference is smaller (-0.59).

34. If only households using fuel for artisan activities are omitted from the sample ($N = 85$), the coefficient on LPG use is practically the same as in model 1, i.e., -1.55.

35. One possible source for systematic bias is that in the 1989 EIH kerosene and firewood price and quantity information was obtained on a weekly basis, whereas LPG information was obtained on a monthly basis. However, it is difficult to see how this would consistently bias the results in one direction or the other.

36. From 1989 EIH data.

37. Shortages may be real, given the monopoly on domestic supply and the policy of restricting imports, but sometimes they are caused by supplier speculation when a price hike is expected. For example, in June 1997, shortages occurred in La Paz and El Alto, resulting in long lines of frustrated consumers ("Fiscalía inció investigación

sobre escasez de gas licuado," *Los Tiempos*, Cochabamba, Bolivia [June 8, 1997], p. A9).

38. Similar results are obtained when total expenditures, total income, or per capita income are included instead of per capita expenditures in the fuel-expenditure regression.

39. Unless otherwise stated, in this article "statistically significant" means that the parameter estimate is not statistically different from zero at the 10% significance level.

40. This lack of uniform price data means that substitution elasticities cannot be calculated.

41. According to Hernán Zeballos H., *Agricultura y desarrollo económico II* (Agriculture and economic development II) (La Paz: Centro de Información para el Desarrollo, 1993), the department of Chuquisaca (where the city of Sucre is located) is 34.5% forested, the department of Cochabamba (where Cochabamba, Quillacollo, and Punata are located) is 47.9% forested, and the department of Tarija is 70.3% forested. However, Zeballos also states that all three of these valley-region departments show large areas of deforestation and erosion, particularly the department of Tarija. In addition, the percentage of forested area in a department may not be directly related to accessibility of the resource in the urban areas.

42. Four additional specifications were estimated: (1) omitting households with artisan activities, (2) including per capita income instead of per capita expenditures, (3) using total household expenditures rather than per capita expenditures, and (4) using the whole sample rather than just the valley region. In all cases the effect of an increase of either income or expenditures on the probability of using firewood is negative, although at a declining rate because of a positive parameter estimate on the quadratic term.

43. While the per-capita-firewood-expenditures regression is estimated both separately and as part of the Heckman selection procedure, regression results without correcting for selection are not reported in the tables since the parameter estimates are very similar.

44. Similar results were found when the following four additional specifications were estimated: (1) omitting households with artisan activities, (2) including per capita income instead of per capita expenditures, (3) using total household expenditures rather than per capita expenditures, and (4) using the whole sample rather than just the valley region. One difference in the results is that the parameter estimate on the quadratic term is positive, although not statistically different from zero, when total expenditures are used.

45. In regressions without the selection correction, two of these parameter estimates are statistically significant.

46. Since this sample is for a particular point in time and, thus, for a given income distribution in urban Bolivia, one would not want to extrapolate the effects to those from larger-than-marginal increases in income. A per capita increase of US$5 per month is actually already fairly large for some households, given that mean per capita expenditures in the valley region are about US$50.

47. Sample size is 192 rather than 195 firewood users because of missing predicted values for three households (missing age or education information).

48. Three households at the upper end of the per capita expenditure distribution have an increased probability because the parameter estimate on the quadratic term for per capita expenditures in the probit model is positive.

49. These figures are calculated from population-weighted averages. For the purposes of this prediction exercise, the seven households with the largest decrease in predicted probabilities are considered to eliminate their firewood use after the increase in per capita expenditures. The change in firewood expenditures is predicted for each

household using the parameter estimates obtained from the per-capita-firewood-expenditure equation (table 6, model A).

50. Hoddinott and Haddad (n. 7 above).

51. The same regression was estimated omitting only households with artisan activities, with similar results as in table 4, model 1, for the parameter estimate on the proportion of female earned income. When the female-earned-income indicator is included rather than the proportion, the parameter estimate is negative but not statistically significant.

52. If model A is estimated with the proportion of female-earned income rather than the indicator variable, the results are similar.

53. As seen previously, households that use firewood are more likely to cook for sale (table 1).