Migration and Fuel Use in Rural Mexico[1][2]

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Abstract

Many households in developing countries rely on renewable natural resources as their main source of energy. Collecting and burning firewood requires a considerable investment of time, has negative health consequences, and can cause deforestation and depletion of local resources. A transition from traditional to modern fuels can benefit households by reducing these negative effects. Migration, a quintessential feature of development, may facilitate this transition, but its impacts on fuel choice are theoretically ambiguous. It can reduce the household labor available for firewood collection and provide cash to purchase substitutes; however, it also may contribute to income and increase the demand for home-cooked food and the energy to cook it. Either firewood or gas could be used to meet the resulting increase in energy demand.

To resolve this theoretical ambiguity, I use an instrumental-variables method with household panel data from rural Mexico and investigate the impact of Mexico-to-US migration and remittances on gas expenditures and household labor allocated to firewood collection. Sending a migrant to the United States causes a significant decrease in reliance on firewood collection and an increase in both stove and gas purchases. These findings have potentially far-reaching environmental implications as labor moves off the farm.

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Introduction

Rural households in developing communities traditionally rely on biomass fuels for energy. Use of local, traditional fuels, like firewood, requires a large amount of time, can have negative health consequences, and if enough households rely on the resource, can deplete local resources. Recent research attributes a significant part of global climate change to the emission of soot (black carbon; Bond, et el., 2013) from burning traditional fuels. As incomes rise, households gain access to other types of fuels, but there is no theoretical consensus on how the development process influences the transition away from traditional fuels.

Early studies (Leach, 1992, Hosier & Dowd,1988) hypothesized that households switch completely away from using traditional fuels when they gain access to modern fuels (that is, they move linearly up the 'energy ladder'). This hypothesis has not been supported by empirical evidence (Masera and Straatkamp (2000), Heltberg (2004), Heltberg (2005), Masera and Navia (1997), and Ruiz-Mercado (2011), Hiemstra-van der Horst and Hovorka (2008)); instead households tend to add fuels into their mix, a process called 'fuel stacking' (Mekonnen and Kohlin, 2008). Current research does not adequately address how fuel decisions occur as part of the complex of economic activities in which rural households engage. Therefore, there remains a gap between theory and empirics in explaining fuel-use decisions. Fuel-use studies focusing only on the rural energy sector ((Hosier and Kipondya, 1993, (Guta, 2012)) may miss significant impacts of changes in other economic activities. One of the most quintessential features of economic development is the large-scale movement of people out of rural areas. No research explicitly addresses the interactions between rural out-migration and fuel use.

In this paper, I develop a theoretical framework to explain rural household fuel choice as the result of households choosing fuel amounts to minimize the cost of meeting their energy needs. This framework allows for the *sustained* use of multiple fuel types, and it explains observed fuel-use patterns (i.e., 'fuel stacking') better than the 'energy ladder' hypothesis. The 'energy ladder' represents a corner solution to this more general model. This model has the potential to explain the impacts of economic development on rural fuel choices and energy use. As an illustration, I investigate the impacts of economic development on resource use by establishing a connection between out-migration and the use of different fuels. Migration can affect the cost-minimizing combination of fuels by facilitating investment and changing the incentives households face on the margin.

Biomasss is the most common traditional energy source in the developing world (Environmental Protection Agency Report to Congress on Black Carbon (March 2012). As rural areas develop economically, households begin to adopt other forms of energy (e.g., propane or liquid petroleum gas (LPG)). For example, in Mexico, small trucks travel to many rural communities to sell gas and take away empty tanks. As household incomes increase, gas becomes a viable alternative to firewood for cooking certain foods.

Economic development has several key features likely to affect households' fuel-use decisions. First of all, market integration can increase access and lower the cost of alternative, modern fuels. In addition, access to credit can facilitate investment in the capital necessary to use modern fuels (e.g., a stove). Finally, labor opportunities (including migration) change the value of household time and the perceived cost of collecting fuel, while providing new income sources.

Some researchers have begun to investigate how other-sector activity can influence firewood behavior (Baland et al (2007, Amacher et al (1996) and Amacher et al (1999)), but they do not explicitly address fuel choice and transition. For example, Amacher, et al. (1996) find evidence that economic linkages across sectors play an important role in the non-market activity of firewood collection. Labor market opportunities and the availability of substitutes affect firewood use. In this paper, I extend this literature to examine fuel-choice decisions.

Why care about rural fuel use?

Obtaining energy comprises an important part of the economic lives of many poor households. Understanding the transition away from traditional fuels (firewood) is an important economic question for many reasons. The four main reasons include:

1. *Health concerns*
   According to the US Environmental Protection Agency, heavy use of firewood can cause bronchitis, lung disease, heart disease, and premature death. The data used in this study confirm this as people who cook with firewood have a significantly higher probability of having poor health. The majority of households do not use improved wood-burning cook-stoves and therefore cook over an open flame indoors. This can exacerbate the health concerns associated with firewood use.
2. *Environmental impacts*
   When a large proportion of a population relies on firewood for cooking and heating it can put pressure on environmental resources. In areas where fallen trees and limbs cannot meet the needs of households, people must cut live trees to use for firewood. In extreme cases this can cause forest depletion, increased erosion, and a loss of habitat and biodiversity. Protecting these resources presents a greater challenge when people rely on the local resource for energy.
3. *Climate change*
   Burning firewood releases more CO_2 into the air than other plausible alternative fuels. For example, burning wood releases 0.39 kg of CO_2 per kWh of energy produced while kerosene releases only 0.26 kg of CO_2. Even coal releases less CO_2 per kWh of energy produced (0.37 kg) (engineeringtoolbox.com). In addition to CO_2 emissions, recent research has shown that soot (black carbon) emitted from firewood combustion could be a significant contributor to recent changes in the global climate (EPA Black Carbon Report-- http://www.epa.gov/blackcarbon/). This implies that as people shift away from the use of firewood, there can be rapid reductions in climate change because of the relatively short life of soot in the atmosphere. Some researchers attribute unexplained slow-downs in global temperature increases to fuel switching in developing countries (Bond et al, 2013).
4. *Quality of life*
   Collecting firewood can take up a lot of time and that time may have a high opportunity cost. For example, in 2010, according to the Mexico National Rural Household Survey (Spanish acronym: ENHRUM), households spent an average of 4.89 person-hours per trip when collecting firewood. This time could be better used in more productive activities such as agriculture. Firewood collection could also take time away from a household's leisure. Poor management of scarce forest resources can mean that each household spends more time than necessary collecting firewood. Adoption of gas stoves can free up time for more productive uses.

Identifying factors that influence the shift away from firewood use represents an important economic challenge with implications for both efficiency and quality of life for rural households. I investigate firewood and gas use in the context of rural Mexico and explore the market-nonmarket linkage between firewood collection, gas expenditures, and out-migration.

Mexico as a case study

Rural Mexico provides an ideal context to investigate the impact of migration on fuel use. In rural Mexico, 27% of households had at least one migrant in the United States in 2007. 41% had a migrant somewhere within Mexico. Migration may provide households with higher incomes while at the same time leaving them less labor time at home (including for firewood collection). Therefore, it may have an impact on energy use and fuel decisions. In the next section, I develop a household-producer model that shows how firewood collection has strong potential within-household linkages to other market activities and how these connections influence cost-minimizing fuel choices. I then use a panel dataset to empirically estimate the impact that migration has on firewood and gas use in rural Mexico.

Household-Production Model

Fuel as input to household production

Household-producer models in which decision-makers produce output and consume all or some of this output while buying other goods on the market (Singh, Squire, and Strauss, 1986; Taylor and Adelman, 2003; Becker, 1965) form the base of the theoretical model presented in this paper. Firewood and gas represent inputs into a home-produced "z-good," as Becker labeled it. Because most households collect their own firewood (only around 3% of firewood users in rural Mexico purchase all their firewood), it represents a non-tradable input to a non-tradable home-produced good. Energy demands drive the demand for firewood and gas.

A static model of household fuel choice

A typical rural Mexican household has many non-marketed inputs and outputs. For example, imperfect substitutability of hired and family labor can result in a household-specific valuation of time. In addition, transaction costs can create a situation in which food producers value their own production at a different price than could be received on the market. For example, it may be cheaper to demand food from own production than to travel to a market to purchase from others. In this situation a household-specific (shadow) price emerges for non-tradable inputs (e.g., labor) and outputs (e.g., corn). Shadow prices have the potential to create strong linkages across activities, both traded and non-traded, within households, just as endogenous local prices transmit influences across households.

The household as economic agent maximizes its utility of consumption while allocating its labor endowment among various activities, including agricultural production, firewood collection, cooking, consuming leisure, and migration.

The household-producer model in this context captures key features of fuel choice. First, a household-level decision-maker buys goods on a market, creates a home-produced good (e.g., food), and enjoys leisure time. Firewood and gas represent inputs into the production of the home-produced good. Firewood is produced using a production function that converts time and capital (e.g., animal services) into firewood output. The main input into this activity is the time it takes to collect firewood. Imperfect labor market integration in rural Mexico means that the opportunity cost of time differs from the market wage. For simplicity, I assume a missing market for family labor; thus, time is a fixed factor with an endogenous shadow wage. The household can earn income locally by selling the output of its agricultural production in the market at price P_F. Production, *A(),* is also a function of labor, L_c.

Gas represents an alternative to firewood for cooking energy. A household chooses how frequently to cook with wood versus gas. A large portion of rural Mexican households (~71%) have both a gas stove and a wood-burning stove. This means that household cooking capital, $\overline{K}_z$, contains an element $\overline{K}_{z,s} = 1$ (the household has a gas stove) or 0 (only a wood-burning stove). For any given meal a household with a gas stove can use firewood and/or gas. Therefore, fuel demand is modeled as a continuous decision as opposed to a discrete choice between different fuels. With no gas stove ($\overline{K}_{z,s} = 0$), firewood represents the only fuel option.

Households also decide how many members migrate, based on expected remittances and migration costs, including the opportunity cost of losing the migrant's labor from home activities. (Migration also results in fewer mouths to feed at home.) In reality, the migration decision has a major dynamic component as households may give up labor in the short run for remittances and investment in the medium and longer terms. These dynamics are ignored in the model for now; I focus on the connections between migration, remittances, and energy use. Finally, a household may have exogenous income either from government programs and/or from private transfers.

The model takes the following form where households choose how to allocate their labor and where to spend their income in order to maximize household utility:

$$\max_{x_c, x_z, x_l, L_F, L_z, L_c, G, \delta} U\left(\frac{x_c}{\delta}, \frac{z}{\delta}, x_l\right) \quad s.t.$$

$$P_c x_c + P_G G = D\big((1-\delta) * \bar{L}; a\big) + P_F A(L_c) + \boldsymbol{\bar{Y}} \qquad (\lambda)$$

$$z = f[F(L_F, \bar{R}_F, \bar{K}_F), G, L_Z, \bar{K}_z, v] \qquad (\mu)$$

$$L_F + L_z + L_c + x_l = \delta\bar{L} \qquad (\rho)$$

Where $x_c, z,$and x_l represent the quantities of store-bought goods, home-produced food, and leisure consumed per unit of potential labor in the household. The proportion of the household living at home is $\delta \leq 1$, which also represents the proportion of the labor endowment in the household. Per capita goods consumption contributes to household utility. The household allocates its time endowment, $\bar{L}$ (which can also be considered the potential labor in the household) among firewood collection (L_F), cooking (L_z), leisure (x_l), farm production (L_c)), and migration to the US ($(1\ \delta) * \bar{L}$). The household receives no utility from a migrant's leisure time. The household can also buy gas G, to use in cooking. F represents the production function for firewood collected while f represents the production function for home-cooked food.

Part of the household decision includes how much of the household's labor endowment to send to the United States, based on migration costs and remittances. Remittances are assumed to weakly increase in labor abroad. 1-δ represents the proportion of labor sent abroad and remittances, D, depend on the amount of labor sent and on a, migration costs. Finally, the household receives exogenous income, $\boldsymbol{\bar{Y}}$, which could come from government or private transfers independent of current migration. In the

Lagrangian the budget constraint has the multiplier λ and the subsistence constraint for home-cooked food has the multiplier μ. ρ is the multiplier on the household labor constraint.

The first-order conditions corresponding to this optimization problem imply the following about household labor allocation and consumption:

$$1.\ \frac{U_1}{U_2} = \frac{P_c}{\frac{\mu}{\lambda}}, \qquad 2.\ \frac{U_1}{U_3} = \frac{\delta P_c}{\frac{\rho}{\lambda}},$$

$$3.\ \frac{\delta U_3}{U_2} = f_3 = f_1 F'(L_F) = \frac{\frac{\rho}{\lambda}}{\frac{\mu}{\lambda}}, \qquad 4.\ P_F A'(L_c) = \frac{\rho}{\lambda}, \qquad 5.\ f_2 \frac{\mu}{\lambda} = P_G$$

$$6.\ U_1 \frac{x_c}{\delta^2} + U_2 \frac{z}{\delta^2} = \left(-\lambda \frac{dD}{d\delta} + \rho\right) \bar{L}$$

The shadow value of home-cooked food emerges from these conditions $\left(\frac{\mu}{\lambda}\right)$; it depends on the household's preferences and labor availability. The conditions show that the household makes consumption and production decisions *as if* the price of the home-cooked good equaled $\frac{\mu}{\lambda}$. The shadow value of time is $\frac{\rho}{\lambda}$.

Conditions 1 and 2 state that the household equates the ratio of the marginal utilities of consumption to the ratio of the prices (or shadow price) of any two consumption goods. 2 contains an adjustment because leisure is not measured per capita.

Conditions 3, 4, and 5 show that the value of the marginal product of each input equates to the marginal cost of that input. Equation 3 demonstrates that the value of the marginal product of labor collecting firewood emerges from its value as an input to the consumption good, z. Therefore the ratio of the marginal benefit of leisure to z-good consumption equates to the ratio of their shadow prices.

These first-order conditions provide several interesting insights. First, $\frac{\rho}{\lambda}$ represents the marginal value (opportunity cost) of time in all household activities, or the shadow wage. At the optimum, it is equated with the marginal benefit of time in each activity.[4] The shadow wage is determined by a number of factors, including household size, and preferences for consumption and leisure. *Ceteris paribus,* larger households have a higher labor supply and a lower shadow wage. This translates into cheaper firewood because the cost of firewood is tied to the value of time. A strong preference for home-cooked meals could increase the shadow wage by increasing the demand for labor. Based on these first-order conditions, households allocate labor to the various activities, including firewood collection.

Figure 1 demonstrates how an endogenous marginal money-valuation of a non-marketed good (home-cooked food) equates to a market or shadow price and, in turn, determines the household's labor allocation to firewood collection and gas purchases. The left graph in figure 1 has an upward sloping labor supply curve, because the value of time is endogenous; the right graph has an infinitely elastic supply of gas because the household takes the price as given. The labor supply curve slopes upward because of a decreasing marginal utility of leisure and home-cooked food (the opportunity cost of collecting firewood increases as more time is spent collecting). The equilibrium represents the household-specific cost-minimizing combination of gas and firewood that achieves the required energy to produce the optimal amount of home-cooked food.

[4] Possible effects of intra-household dynamics on efficiency are not addressed in this model.

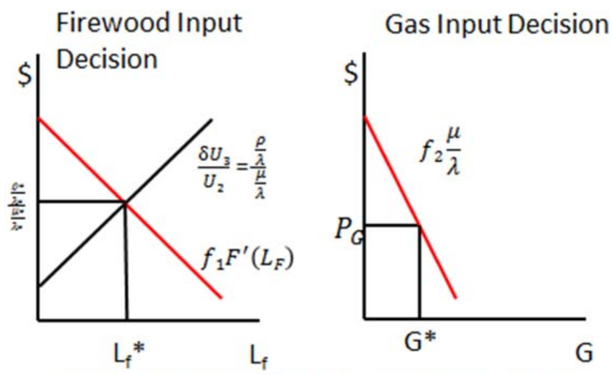

Figure 1: Household producers equate the value of the marginal product of each input with their cost. Households choose the cost minimizing combination of gas and wood. Marginal values depend on household preferences.

The last condition [# 6] states that the marginal utility of having a migrant abroad equates to the marginal value of labor/leisure in the household, accounting for the fact that less consumption is required in a household with fewer members. In reality, this decision is a discrete decision about the number of migrants to send abroad, but modeling it as continuous captures the intuition that a household member stays in the household unless s/he can contribute more to household utility by migrating and sending money home. (Of course, this ignores the fact that some household members may migrate for personal reasons not solely motivated by household-level decisions. I also abstract from the fact that the proportion of labor abroad may not equal the proportion of the household abroad because some household members (e.g., young children and the elderly) may not supply labor to household activities.

An interior solution to this model includes the use of both firewood (a traditional fuel) and gas (modern fuel). This is the outcome most consistent with fuel 'stacking,' as households could use multiple fuels on a sustained basis. On the other hand, corner solutions in which a household uses only firewood or only gas represent different stages in the fuel ladder model. They can result if one fuel becomes relatively cheap. The fuel ladder model applies only if relative costs change substantially.

In this model, the value of firewood to the household comes only from the output produced using firewood; it is a derived value. Because of this, the decision to collect firewood is driven purely by the demand for the z-good and the tradeoff between the cost of gas and the labor costs associated with firewood collection. Given this, the household minimizes the cost of producing the optimal amount of home-cooked food by choosing the optimal mix of firewood and gas. In real life, food cooked with gas may not perfectly substitute for food cooked with firewood. Anecdotal evidence suggests a strong preference in some cases for certain foods (e.g., tortillas) cooked using firewood. While recognizing this distinction, the current model abstracts from these complexities in order to highlight the economic incentives a household may face to substitute on the margin towards one input or another.

The migration decision affects firewood collection through the loss of labor supply in the household. In the face of decreased labor availability (and higher shadow wages), a household pulls some labor out of firewood collection to use in other activities; meanwhile, remittances can provide liquidity to purchase gas. Of course, fewer mouths to feed may mean lower overall demand for cooked food and further decrease the need for firewood. On the other hand, strong preferences for home-cooked food, possibly fueled by remittances, could keep labor in firewood collection.

A dynamic decision

The household decisions presented thus far take cooking capital as given. This allows the firewood collection decision to depend continuously on other factors affecting the household. In reality, the household makes the decision to invest in a gas stove or not and then decides how to allocate labor to multiple uses. Without a gas stove, gas does not represent a feasible substitute for firewood in the household's energy mix. A dynamic investment model is thus needed to explain the decision to invest in a gas stove.

In the above model, $\overline{K}_z$ is assumed to include a gas stove. In reality, the decision to invest in a stove is influenced by many factors, among them migration and household income, including remittances. A simplified two-stage model endogenizes the investment decision of whether or not to buy a gas stove.

If $\overline{K}_{z,s} = 0$ in time 0, a household must decide whether or not to invest in a gas stove. This first-stage decision affects current income available for other uses. First-stage utility is:

$$U_0(I(\overline{L}, D(\delta), \overline{\boldsymbol{Y}}) - r)$$

Where I is total income in the period and r is the cost of stove investment. $r_t > 0$ if $s_t = 1$ where $s_t = 1$ if a household purchases a stove in period t. $r_t = 0$ otherwise.

Next, a household makes consumption and labor allocation decisions as in the static model. If $s_t = 1$, the household chooses its energy input mix required to meet the energy demands of $\bar{z}^1$, which is the solution to the static model when $\overline{K}_{z,s} = 1$. To do this, a household minimizes the cost of energy inputs, or

$$\min_{L_F, G} \quad wL_F + P_G G \quad s.t.$$

$$z = f[F(L_F, \overline{R}_F, \overline{K}_F), G, L_Z, \overline{K}_z, v] = \bar{z}^1$$

…where $\bar{z}^1$ comes from the optimization problem presented above. This decision in the full model produces an optimized value of utility, $U^1{}_t$.

If $s_t = 0$, $\overline{K}_{z,s} = 0$ and a household uses L_F so that

$$z = f[F(L_F, \overline{R}_F, \overline{K}_F), 0, L_Z, \overline{K}_z, v] = \bar{z}^0$$

…which gives $U^0{}_t$. In this case the household does not have the option to integrate gas into its energy mix because it does not have a gas stove. Gas purchase is constrained to be zero, resulting in a lower utility in periods after the stove investment is made (i.e., $U^1{}_t \geq U^0{}_t$). Obtaining the stove implies decreasing current period utility and requires cash, defined as r. Liquidity constrained households may not be able to make the investment.

The stove investment decision trades off the current expense with the utility gain associated with the ability to include gas in the mix of inputs used for cooking. Formally, for a discount rate of ϕ,

$$s = 1 \quad if \quad U_0(I(\overline{L}, D(\delta), \overline{\boldsymbol{Y}}) - r) + \sum_{1}^{T} \frac{U_t{}^1}{(1+\phi)^t} > U_0\big(I(\overline{L}, D(\delta), \overline{\boldsymbol{Y}})\big) + \sum_{1}^{T} \frac{U_t{}^0}{(1+\phi)^t}$$

$$s = 0 \quad otherwise$$

From this two-stage decision model, it becomes apparent that the migration decision may influence the household stove investment decision by providing cash for the stove investment as well as altering the optimal local labor allocation. Without a gas stove, households are less able to smoothly include gas in their energy mix. This 2-stage decision is used in the empirical exercise, below, to investigate the mechanisms by which migration influences households' fuel mix.

Data—*Encuesta Nacional a Hogares Rurales de Mexico*

The household data for this study come from the Mexico National Rural Household Survey (Spanish acronym ENHRUM), carried out jointly by El Colegio de Mexico and UC Davis. The 3-year panel contains household survey data that, in its first year (2002), was nationally representative of rural Mexico. The following two rounds were in 2007 and 2010. Rural is defined as communities with between 50 and 2,499 people. Originally, the sample came from 80 communities in 14 states in Mexico's 5 census regions. In 2010 not all regions could be surveyed due to increased violence and budgetary considerations. Because of this, I use the first two rounds of the survey. These data make it possible to explore the role of firewood and gas in rural Mexico and to investigate the causal impact between migration and fuel use.

The role of firewood and gas in rural Mexico

Both firewood and gas play an important role in rural Mexican economic life. Most households with gas stoves (61% in 2007) continue to cook at least occasionally with firewood. Traditional foods (e.g., tortillas, beans, and tamales) are often cooked with firewood. However, if households are able to purchase other energy sources they cook many foods with a gas stove (e.g., soup, coffee, etc.), choosing the types of food they consume and the type of fuel they use when cooking. These findings are consistent with the theoretical framework presented in section 2.

Table 1 shows that over half of households in rural Mexico collect their own firewood; the proportions have remained fairly constant since 2002. This illustrates that not many households have completely stopped collecting firewood over the 8 year timespan of the data. For this preliminary analysis I include

2010 survey results and only households that were surveyed all 3 rounds. Econometric analysis drops 2010 results and includes all households surveyed in rounds 1 and 2.

Table 1: Proportion of HHs that Collect Firewood

Year	2002	2007	2010
Proportion	0.57	0.53	0.58
With remit	0.54	0.55	0.49

Relatively few households transition from collectors to non-collectors. Table 2 reveals that 45% collected in both years, 34% did not collect either year, and only 8% stopped collecting. Interestingly, some households that did not collect firewood in 2007 began collecting in 2010. Approximately three percent of households buy all of their firewood and do not collect it themselves.

Table 2: How constant is firewood collection (proportions)?

		2010	
		collector	non-collector
2007	collector	0.45	0.08
	non-collector	0.13	0.34

Table 3 shows how selected socio-economic characteristics of firewood collectors compare with those of the overall population of rural Mexico. Firewood users tend to have lower incomes on average. In 2010 the difference in remittances received changed substantially between firewood collectors and non-collectors. Between 2007 and 2010, there was a drop in the proportion of households that receive any remittances (likely due to the US recession), but firewood collectors saw a bigger drop.

Table 3: Firewood Collection, Remittances, and Income (averages, in nominal pesos)

	2002	2007	2010
Remittances if receive	23215	29993	39448
Remittance if collect firewood and receive	23293	29157	26706
Proportion of HHs with remittances	0.14	0.20	0.14
Proportion of firewood collectors with remittances	0.14	0.21	0.11
Total income	40547	42973	55977
Total income for firewood collectors	31460	38875	48453
Household size	4.86	5.05	4.859
Number of days conditional on collecting	115.21	123.34	139.40
Person-hours per day of collection			4.89
Firewood users with non-ag job			0.33
Firewood users with Oportunidades			0.43
Overall proportion with non-ag job			0.39
Overall proportion with Oportunidades			0.35

Table 3 also shows that firewood collection takes up a significant portion of the total time of households that collect. Firewood-collecting households collect firewood almost every other day, and when they do they spend an average of almost 5 person-hours collecting.

Table 4 demonstrates the role of gas in rural Mexican households and how it interacts with firewood as an energy source. The majority of households include gas in their fuel mix. Between 2002 and 2007 there was a significant increase in the percentage of households cooking with both wood and gas.

Table 4: Role of Gas in Rural Mexican Fuel Use
(Percent unless otherwise indicated)

	2002	2007
Households that include gas in fuel mix	72	74
Households that cook only with gas	43	39
Households that cook only with firewood	28	25
Households that use gas and firewood	29	36
Average expenditure on gas (2002 Pesos)	118	145
Average expenditure on firewood (2002 Pesos)	24	25

Consistent with the literature on fuel transition, descriptive statistics support the fuel stacking hypothesis over the energy ladder. Despite the use of gas, firewood collection continues to play a large role in rural Mexico and is a time consuming activity for the households that collect.

Empirical model

Summary statistics presented in the previous section suggest that there is a connection between migration and fuel use in rural Mexico. A more rigorous approach is needed to explore the causal impact of migration on fuel choice.

The modeling exercise presented earlier in this paper provides direction for an empirical analysis of the impacts of migration on firewood collection and gas purchasing decisions. I use the data from the ENHRUM to investigate the causal linkage between migration and the use of firewood and gas in rural Mexico. The theoretical exercise produced ambiguous results concerning the impacts of migration on firewood use, as increased remittances may increase the demand for home-produced food requiring energy input. However, less family labor and increased remittances may facilitate a transition towards the use of gas. I investigate this linkage first in the context of the one-stage theoretical model, in which a household chooses only how much labor to allocate to collecting firewood. For this, I assume the stove investment decision has already taken place and only include households with a gas stove. I then estimate a two-stage model, in which an investment decision precedes the labor allocation decision. Throughout this analysis I use White's heteroskedasticity-consistent (HC) standard errors.

Identifying the impact of migration is not straightforward because while migration can affect fuel use, households may choose to migrate from areas where resources are not readily available. This potential endogeneity problem makes identification of the causal impact of migration more challenging. Because the decision to migrate may be endogenous to the availability of fuel, I propose the following identification strategy.

US Migration and fuel use for households with gas stoves

I investigate the impact of the US migration decision and associated remittances on fuel use only for those households that include gas in their energy mix (i.e., the households that already invested in a gas stove). I begin by estimating the impact of migration on firewood collection. The reduced-form model of the impact of migration on firewood collection takes the following form:

$$LnDays_{i,t} = \alpha + \beta Migrate_{i,t} + X_{i,t}\gamma + \varepsilon_{i,t}$$

Where "migrate" takes on the value of one if a household has a migrant in the US in year t (t= 2002, 2007) and a zero if not. The coefficient on this variable contains the impact of the 1-0 migration decision. X controls for other household characteristics, which include the median community wage, household size, total income, ethnicity (a dummy variable indicating if a household head speaks an indigenous language), and schooling (the number of adults with no higher than primary education). Regressions also include a time trend.

Here, $E(X_i \varepsilon_i) \neq 0$ because people may migrate because of a lack of abundant resources in an area. Two-stage least-squares, with proper instruments, identifies the true impact of migration on firewood collection.

Migration networks provide instruments for a household migration decision through their impact on *a* from the theoretical model. Connections in the destination area can lower the costs and uncertainty associated with moving to an unfamiliar place. Because lowering migration costs increases the perceived net value of sending an additional migrant, a household with lower migration costs is more likely to send a migrant abroad. In this analysis, two variables are used to instrument for migration. One is a dummy variable measuring whether or not the household has a family member who migrated in the past. If the father of a household head worked for some time in the US, he likely established a network there. In addition, Taylor and Lopez-Feldman (2010) use an indicator variable equal to 1 if a household is in a community that participated in the *Bracero* program, under which Mexicans could legally work in the United States between 1942 and 1964. This program was available to some communities and not to others, and while it may not have been exactly random (it followed the railroad in many cases), it provides an improvement over treating migration as exogenous. A community that participated in the *Bracero* program more likely has established networks in the United States, making it more likely for other households to migrate. Results do not depend qualitatively on the choice of instrument. Given this, the first stage regression is:

$$Migrate_{i,t} = \theta + Z_i\gamma + X_{i,t}\vartheta + u_{i,t}$$

Where Z could be a dummy variable indicating whether or not the household is in a *Bracero* community or the father of the household head lived in the United States at some point in the past. $\widehat{Migrate}_i = \theta + Z_i\gamma + X_i\vartheta$ provides an instrument for the endogenous migration decision, and the new model is:

$$LnDays_{i,t} = \alpha^{IV} + \beta^{IV}\widehat{Migrate}_{i,t} + X_{i,t}\gamma^{IV} + \varepsilon_{i,t}$$

Finally, as a placebo test, I explore whether migration has an impact on firewood use for households that do not have access to a gas stove. These households do not have the option of smoothly changing their fuel mix and firewood has to meet all energy demands. After controlling for changes in household size, there should be no impact of migration on firewood use (assuming migrants' energy needs do not differ systematically from those of non-migrants).

The above identification strategy is repeated using gas purchases as the LHS variable to identify the impact of migration on gas purchases. Combining this with the previous analysis, and investigating changes in firewood purchase behavior (also using IV), we can see how migration influences the optimal mix of firewood and gas as energy inputs for rural Mexican households.

Two-stage model

We are also interested in knowing whether migration induces (less labor time available to collect firewood) or enables (increased liquidity from remittances) households to include gas in their fuel mix. An instrumental variables linear probability model was estimated to determine whether migration increases the probability of owning a gas stove. This regression takes the following form:

$$Prob(have\ a\ gas\ stove)_{i,t} = \alpha + \beta^{IV}\widehat{Migrate}_{i,t} + X_{i,t}\gamma + \varepsilon_{i,t}$$

…where the migration decision is instrumented as above. IV Probit regression would be desirable, but because the RHS endogenous variable is not continuous, IV Probit does not give an unbiased estimate of β^{IV}. The linear probability model gives an estimate of the average effect (http://www.stata.com/meeting/chicago11/materials/chi11_nichols.pdf). Probit results are also presented but contain the endogenous decision to migrate. The endogenous dummy variable is equal to one if a household purchased gas in a given year. If not, the variable is 0. The survey did not directly ask if a household owned a gas stove.

I use the results of this first-stage model to model how migration affects expenditure on gas, controlling for the fact that we can only observe gas expenditures for households that have already made the decision to invest in a gas stove. A Heckman selection model makes use of the Probit results to quantify the impact of migration on gas expenditures while controlling for the stove investment decision. Standard errors are adjusted using the method proposed by Lee (2001) because the second stage uses the estimated parameters from the first stage. If ${Lngas^*}_{i,t}$ denotes gas purchases observed conditional upon a household having a stove, this model takes the following form:

$$ {Lngas^*}_{i,t} = \alpha + \beta \widehat{Migrate}_{i,t} + X_{i,t}\gamma + \rho\sigma_{\varepsilon}\lambda(W_{i,t}\theta) + u_{i,t} $$

…where λ is the inverse-Mills ratio (The Mills-ratio is the normal CDF divided by the normal PDF) evaluated at the point $W_{i,t}\theta$. $W_{i,t}$ are variables influencing the stove investment decision and are similar to the *X*'s but include community adoption rates. θ are the parameters from the first stage. ρ is the correlation of between $u_{i,t}$ and $\varepsilon_{i,t}$ and σ_u is the standard deviation of the error in the second-stage regression, which accounts for the fact that households purchasing gas have self-selected into the group that can include gas in their fuel mix. Again, I instrument for the migration decision.

National migration

Finally, to test whether migration within Mexico has a similar effect I repeat the above exercises for internal migration, using network effects as an instrument for migration within Mexico as well. To instrument for within-Mexico migration I use a variable equal to one if a household head's parent migrated within Mexico, zero otherwise.

Econometric results

Migration and fuel mix for households with gas stoves

The econometric analysis is carried out using household data from 2002 and 2007. The migration decision appears to have a significant effect on firewood collection behavior and fuel use. Table 5 presents the results of regressions exploring the impact of migration on the number of days a household spends collecting firewood for households with a gas stove. Column 1 shows pooled (potentially biased) OLS coefficients, which highlight the difference between migrant and non-migrant households' firewood collection. Column 2 shows the pooled IV results. There is a negative and significant relationship between sending a migrant and firewood collection. On average, the expected number of days collecting firewood falls significantly, by 3.4%. The results of a random effects[5] model, presented as a robustness check, are qualitatively similar. Finally, the impact of migration on firewood collection in households with no gas stove is presented as a placebo. As expected, without a stove, migration (along with the other factors) does not significantly alter firewood collection.

Table 5: Impact of US Migration on Days Collecting Firewood				
t-stats in parenthesis	LHS: Days per year collecting firewood			
VARIABLES	OLS	IV	RE	IV Placebo
US migrant	-0.225**	-3.419**	-0.220**	-7.373
	(-2.286)	(-2.058)	(-2.248)	(-0.849)
Wage (log)	-0.832***	-0.394	-0.824***	0.391
	(-5.415)	(-1.135)	(-5.248)	-0.368
Hh size (log)	0.217***	-0.452	0.221***	-0.311
	-2.636	(-1.183)	-2.637	(-0.463)
Hh income (log)	-0.0103	0.145	-0.00597	0.321
	(-0.254)	-1.451	(-0.148)	-0.985
Indigenous	0.00525	-0.273	0.0145	-0.447
	-0.0383	(-1.104)	-0.106	(-0.446)
Only primary school	0.0286*	0.163**	0.0285*	0.228
	-1.869	-2.201	-1.818	-0.903
Year	0.385***	0.517***	0.378***	0.74
	-4.028	-3.229	-4.054	-0.898
Constant	6.445***	4.280***	6.374***	-0.602
	-9.285	-2.777	-9.006	(-0.0901)
Observations	823	819	823	676
R-squared	0.067			
Robust t-statistics in parentheses				
*** p<0.01, ** p<0.05, * p<0.1				

[5] There is not sufficient variation in the within-household migration decision to identify a panel fixed-effects model

Table 6 presents the results of the IV model showing the causal impacts of migration on gas and firewood purchases. Migration increases expenditure on gas by around 2%, while having an insignificant impact on firewood purchases. In combination, the above results shows a clear pattern of migration causing households with gas stoves to increase the portion of gas in their fuel mix while decreasing their reliance on firewood.

Table 6: IV Estimation of Impact of US Migration on Fuel Expenditures

t-stats in parenthesis	(1)	(2)
VARIABLES	Gas expenditure	Wood expenditure
US migrant	1.954***	-0.0816
	(4.348)	(-0.147)
Wage (log)	-0.123	1.007***
	(-0.678)	(6.060)
Hh size (log)	0.411***	-0.0714
	(4.754)	(-0.751)
Rate of stove use	4.263***	0.525***
	(22.01)	(2.879)
Hh income (log)	0.139***	-0.0281
	(4.530)	(-1.004)
Indigenous	-0.672***	0.736***
	(-4.961)	(5.493)
Only primary school	-0.142***	0.0174
	(-6.577)	(0.702)
Year	-0.0676	-0.244**
	(-0.759)	(-2.506)
Constant	-0.446	-3.439***
	(-0.602)	(-5.247)
Observations	2,945	2,945
R-squared	0.444	0.035

Robust t-statistics in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Gas stove investment

The two-stage least-squares linear probability model produces a large and significantly positive impact of US migration on the probability that a household invests in a gas stove. Table 7 shows the impact of migration on this probability using the IV linear probability model and a Probit model. The point estimate of the linear probability model suggests that having a migrant increases the probability of having a gas stove by 33%. The average effect of migration implied by the Probit with an endogenous RHS variable is 32%, not significantly different from the IV estimate. Because it does not differ qualitatively from the IV results, I use the Probit in the first stage of the Heckman selection model to generate the inverse-Mills ratio to be used in the second stage gas expenditure regression.

Table 7: Migration and Gas Stove Investment

t-stats in parenthesis	(1)	(2)
VARIABLES	IV linear probability	Probit average effects
US migrant	0.334***	0.319***
	(3.388)	(4.236)
Rate of stove use	0.870***	3.295***
	(22.90)	(22.30)
Hh income (log)	0.0254***	0.135***
	(4.393)	(4.972)
Indigenous	-0.0829***	-0.489***
	(-2.815)	(-5.276)
Only primary school	-0.0232***	-0.0708***
	(-5.981)	(-6.579)
Year	-0.0150	0.121*
	(-0.867)	(1.873)
Constant	-0.0788	-2.749***
	(-3.064)	(-8.897)
	(-1.228)	
Observations	3,056	3,070
R-squared	0.427	
Robust t-statistics in parentheses		
*** p<0.01, ** p<0.05, * p<0.1		

Table 8 shows the results of the Heckman selection model, which simultaneously models the stove investment decision and household expenditure on gas. The results of this model take into account the fact that household choose whether or not to invest in a gas stove; gas expenditures are conditional upon this investment. Rho and sigma both differ significantly from zero, indicating the presence of selection. In this case, linear estimates are biased. Migration still represents an endogenous decision, so the analysis is repeated using instrumental variables and including the inverse-Mills ratio on the RHS. Using this method, having a migrant leads to a 2.8% increase in expenditure on gas. This result makes sense, as IV estimation increased impacts compared to OLS. Using the Heckman correction, the impact is slightly smaller with and without instrumental variables. A Tobit model of gas expenditure is included in column 3 as a robustness check, and the results are qualitatively similar to other non-IV results.

Table 8: Heckman Selection and Tobit Estimation			
LHS: Gas Expenditure	Heckman Selection	Heckman Selection with IV	Tobit
US migrant	0.180***	2.790***	0.677***
	(3.494)	(4.927)	(7.032)
Wage (log)	0.0994	0.311	3.136***
	(0.859)	(1.561)	(11.59)
Hh size (log)	0.245***	0.552***	0.183**
	(5.951)	(5.453)	(1.989)
Hh income (log)	0.0428**	0.0656*	0.338***
	(2.143)	(1.864)	(7.769)
Indigenous	-0.346***	-0.373**	-3.161***
	(-3.656)	(-2.467)	(-16.79)
Only primary school	-0.0300***	-0.140***	-0.142***
	(-3.776)	(-4.698)	(-8.420)
Year	-0.0268	-0.366***	-0.457***
	(-0.544)	(-3.327)	(-4.609)
Inverse-Mills ratio		-1.486***	
		(-11.36)	
Constant	3.897***	2.113**	-12.19***
	(7.619)	(2.322)	(-10.54)
rho	-0.750		
s.e.	0.03		
sigma	1.070		
s.e.	0.020		
lambda	-0.810		
s.e.	0.050		
Observations	2,993	2,945	2,957
z-statistics in parentheses			
*** p<0.01, ** p<0.05, * p<0.1			

Table 9 shows that having a migrant within Mexico does not necessarily reduce dependence on firewood collection for energy. Many of the other explanatory variables remain significant but migration within Mexico appears to have different impacts than migration to the US. This suggests the existence of some fundamental differences between domestic and international migration. Potential differences are discussed below.

Table 9: Within Mexico Migration and Firewood Collection	
LHS variable: ln days collecting firewood	
VARIABLES	IV
National migrant	2.107
	(1.255)
Wage (log)	-0.429
	(-1.273)
Hh size (log)	0.579**
	(2.145)
Hh income (log)	0.0236
	(0.452)
Indigenous	0.328***
	(2.845)
Only primary school	-0.0427
	(-0.781)
Year	-0.360
	(-0.701)
Constant	4.521**
	(2.532)
Observations	1,495
Robust t-statistics in parentheses	
*** p<0.01, ** p<0.05, * p<0.1	

Discussion

The results presented in this paper suggest that migration has facilitated the inclusion of gas in the fuel mix of rural Mexican households. Households with migrants are much more likely to own a gas stove, a necessary step to including gas in the fuel mix. For households that have made the gas stove investment, migration leads to less time collecting firewood and a greater expenditure on gas. These results are consistent with the theory presented in this paper: migration changes the cost-minimizing combination of fuels to meet household energy needs. Losing labor and gaining remittances change the relative implicit costs of firewood and gas.

Descriptive statistics and empirical results from this analysis confirm that new fuels do not fully replace traditional fuels. They are consistent with a household-producer model that includes fuel choice as a cost-minimization decision conditional on available capital. Liquidity-constrained households are less able to invest in a gas stove (household income significantly affects the investment decision). Households that do invest in a gas stove do not abandon firewood collection; instead, they add gas to their mix of fuels and choose the optimal amount of each to minimize the cost of satisfying their energy needs. Migration, by relieving liquidity constraints, facilitates gas stove investment, providing households with greater flexibility when choosing fuel inputs. These findings are consistent with other research showing that remittances stimulate investment (Yang, 2008; Taylor, 1999).

In addition to facilitating investment in a gas stove, migration affects marginal decisions because associated remittances allow households to purchase gas on a regular basis. Firewood, in contrast to gas, can be very costly in terms of time but requires no cash outlay in the majority of cases. Migrant households become more labor constrained, increasing the implicit cost of firewood. Because of this, households with migrants spend more on gas even when controlling for whether they self-select into gas stove ownership.

Surprisingly, migration within Mexico has a qualitatively different impact on rural household fuel mixes. While having a US migrant increases the chances of having a stove and decreases the amount of labor allocated to firewood collection, having a migrant in Mexico has no significant impact on either outcome. This is likely due to differences in remittances from migrants at different locations. Investment in a gas stove requires the accumulation of savings and regular gas purchases require a steady flow of income. Migrants in the US are more likely to send remittances home, and the average amount they remit is much higher. In 2007, less than 2/3 of households with national migrants received remittances, while 85% of households with US migrants received remittances. National remittances average just over 11,000 (constant 2002) pesos per year, while remittances from the United States averaged over 25,000 pesos. This difference in remittances could explain the difference in impacts. The relative ease with which internal migrants may come and go from their households of origin might also play a role, by mitigating the negative impact of migration on the household labor supply and thus on the incentives to shift from firewood to gas.

An important lesson that emerges from this research is that migration alone does not facilitate the transition from firewood to gas in migrant-sending areas (although rural to urban migration is likely to lead to more use of gas (Leach, 1992) by migrants themselves). Cash and the right incentives are required in order to encourage households to invest in a gas stove and continually purchase gas. My findings suggest that current urbanization trends in Mexico will have an effect on fuel use in rural communities only if it generates a sufficient flow of remittances into migrant-sending households.

Other factors from this analysis that appear to influence fuel choice include the community wage, household size, total income, and whether a household is indigenous or not. Higher household incomes loosen liquidity constraints and allow investment in gas stoves and periodic purchase of gas. Higher community wages can alter the perceived opportunity cost of firewood collection. The size of households also matters, as more working-age household members can reduce the shadow wage. This changes the cost minimization problem; a lower opportunity cost of labor causes households to shift their fuel use in favor of firewood. Finally, indigenous households are much less likely to include gas in their fuel mix, and they spend more time collecting firewood even if they have a gas stove. Particular attention could be paid to indigenous areas to promote the use of gas for some foods.

Interestingly, community gas stove adoption rates matter a lot for household adoption. This could indicate that some advantages of gas are community specific. For example, communities with easy access to forests may find it relatively cheap to continue using mostly firewood. On the other hand, communities lacking access to forests are more likely buy gas. Market scale also matters: gas must be transported to the community, and gas companies may be more willing to make trips to a community if more households are buying gas. The findings suggest that households anticipate this, and they increase their use of gas accordingly. Better access to gas can increase the probability of stove adoption.

Conclusion

In this paper, I present a new way of modeling fuel switching in rural communities. When a household gains access to a new fuel it does not stop using traditional fuels. Completely switching to a new fuel represents a corner solution in a more general model, in which households continuously choose which fuel to use in an effort to minimize the cost of meeting their energy demands. The cost of gas is a market price, but the price of firewood, normally gathered by the household, is an implicit, shadow value. The model of fuel choice presented here explains the observed persistence of traditional-fuel use when households gain access to new fuels.

A number of questions remain unanswered by this analysis. For example, whole-household migration from rural areas can have implications for overall fuel use since urban households are more likely to use gas. This analysis only looks at households that remain in rural areas. Between 2002 and 2007, the ENHRUM survey had an attrition rate of 12.6 percent, most of which consisted of whole-household migration (Arslan and Taylor, 2011).

Future research should aim to quantify the value of firewood as an input to home production, thus permitting a more complete understanding of the cost-minimizing choice of energy inputs in rural households. The impacts of remittances on rural households deserve more analysis, because they play an important role in determining fuel use. This problem is tricky, as remittance levels are determined endogenously along with other household decisions, and their effects cannot easily be isolated from the loss of labor through migration.

The findings presented here have several broad implications. First, a complete transition away from firewood represents a corner solution in a more general model; introducing a new fuel is not sufficient to replace a traditional fuel. Labor market imperfections imply that households do not value firewood at its market price. Market prices, therefore, are likely to offer little guidance when designing interventions to discourage firewood use. Fuel demand cannot be analyzed in isolation from households' investments in stoves. The initial gas stove investment is a barrier to gas use; once a household invests in a gas stove, it must also be cost minimizing for it to integrate gas into the fuel mix. The framework presented in this paper, I believe, represents an improved way of understanding rural energy use and has potentially far-reaching implications as the movement of labor off the farm increases worldwide.

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