Analysis

Migration and fuel use in rural Mexico ☆

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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 amount of time, has negative health consequences, and can cause deforestation and depletion of local resources if forests are not properly managed. 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 has an income effect that changes the demand for home-cooked food and energy to cook it. Firewood or gas could be used to meet the increase in energy demand. To resolve this theoretical ambiguity, we 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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1. Introduction

Rural households in developing economies traditionally rely on biomass fuels for energy. The 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 (Bond et al., 2013) suggests that black carbon (soot), emitted from traditional fuels, could play a significant role in global climate change. 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 (Hosier and Dowd, 1988; Leach, 1992) hypothesized that households switch completely away from traditional fuels when they gain access to modern fuels (that is, they move sequentially up the 'energy ladder'). This hypothesis has not been supported by empirical evidence (Heltberg, 2004, 2005; Hiemstra-van der Horst and Hovorka, 2008; Masera and Navia, 1997; Masera and Staatkamp, 2000; Ruiz-Mercado et al., 2011); instead households tend to add new fuels into their mix, a process called 'fuel stacking' (Mekonnen and Köhlin, 2009). 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 (Guta, 2012; Hosier and Kipondya, 1993) 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, we 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. Our model has the potential to explain the impacts of economic development on rural fuel choices and energy use. As an illustration, we investigate the impacts of economic development on resource use by establishing a connection between out-migration and the use of different fuels. Our results are robust to multiple specifications

and indicate that migration has facilitated a shift away from reliance on firewood for cooking energy. Migration can affect the cost-minimizing combination of fuels by facilitating investment and changing the incentives households face on the margin.

Biomass is the most common traditional energy source in the developing world (Environmental Protection Agency Report to Congress on Black Carbon (March 2012)). In Mexico, while a variety of biomass fuels exist, firewood represents the dominant form of traditional energy (Masera, 1993). 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 rural villages to sell LPG and take away empty tanks. As household incomes increase, gas becomes a viable alternative to firewood for cooking certain foods. Table 1 demonstrates that, in rural Mexico, gas has become an important source of energy for cooking. Only a quarter of rural Mexican households cook solely with firewood. As gas becomes popular, many households continue to use at least some firewood. Around 60% of rural households use this traditional fuel to cook (see Table 1).

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 (Amacher et al., 1996, 1999; Baland et al., 2007), 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, we extend this literature to examine fuel-choice decisions.

2. Implications of Rural Fuel Choice

Obtaining energy comprises an important part of the economic lives of many poor households. A transition away from traditional fuels may provide benefits to households and society as a whole. The transition may also have some costs. Four areas in which fuel choice can have significant impacts include:

1. *Health*
   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 support 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. *Local environment*
   The local environmental impacts of fuel choice often depend on the institutions that exist for managing local forests. If communal forests (common in rural Mexico) are effectively managed, firewood collection can represent a sustainable productive use of what often are

extensive tracts of land (Ostrom, 1990). Decreasing the demand for communal firewood can affect a village's ability to manage its common property for this traditional use. On the other hand, if forests are not managed and village populations are large, the demand for firewood can exceed the forest's ability to produce it, resulting in increased length of collection trips and in some cases forest depletion, increased erosion, and a loss of habitat and biodiversity. Protecting overused forests presents a greater challenge when people rely solely 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) (carbon content from 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 (United States EPA, 2012). This implies that as people shift away from the use of firewood, there may be near-term reductions in adverse climate impacts because of the relatively short life of soot in the atmosphere.

4. *Quality of life*
   Collecting firewood can take significant amounts of time and has high opportunity costs. For example, in 2007, according to the Mexico National Rural Household Survey (Spanish acronym: ENHRUM), households spent an average of 3.95 person-hours per trip when collecting firewood. This time could potentially 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 all households spend more time than necessary collecting firewood (Ostrom, 2008). Adoption of gas stoves can free up time for more productive uses while continuing to meet household energy demands. At the same time, food cooked with firewood can have cultural value. Rural Mexicans prefer certain traditional foods (e.g., beans and tortillas) cooked with firewood. As gas becomes more common, some traditional foods may lose cultural importance, and evidence suggests that as households substitute away from traditional foods they consume food with lower nutritional value (Kuhnlein and Receveur, 1996).

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. We 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.

2.1. 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, we 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. We then use a panel dataset to empirically estimate the impact that migration has on firewood and gas use in rural Mexico.

3. A Household Production Model of Fuel Use

Household-producer models in which decision-makers produce output and consume all or some of this output while buying other

Table 1
Role of gas in rural Mexican fuel use (percent unless otherwise indicated).

	2002	2007
Only gas	43	39
Only firewood	28	25
Both	29	36
Avg. annual gas expenditure (2002 Pesos)	1414	1857

goods on the market (Becker, 1965; Singh et al., 1986; Taylor and Adelman, 2003) 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.

In reality, the decision to migrate has many dimensions. It is not always the result of a coordinated household decision. Individuals may make decisions on their own for reasons that go beyond conventional economics. Therefore, the household modeling framework represents an abstraction from reality. Despite this, the household model provides a useful framework for understanding the linkages between consumption decisions and labor allocations that occur within households.

3.1. A Static Model of Household Fuel Choice

A typical rural Mexican household utilizes many non-marketed inputs and outputs which complicate the analysis of household decision making. 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 village prices transmit influences across households.

The household as an 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, we 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; we focus on the contemporaneous and static 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, in which households choose how to allocate their labor and where to spend their income in order to maximize household utility (corresponding Lagrangian multipliers are in parentheses to the right of each constraint):

$$\max_{x_c,x_z,x_l,L_F,L_z,L_c,G,\delta} U\left(\frac{x_c}{\delta},\frac{z}{\delta},x_l\right) s.t.$$
$$P_c x_c + P_G G = D\big((1-\delta)*\overline{L};a\big) + P_F A(L_c) + \overline{Y} \quad (\lambda)$$
$$z = f\big[F(L_F,\overline{R}_F,\overline{K}_F),G,L_Z,\overline{K}_z,v\big] \quad (\mu)$$
$$L_F + L_z + L_c + x_l = \delta\overline{L} \quad (\rho)$$

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, $\overline{L}$ (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 ($(1-\delta)*\overline{L}$). 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. $1-\delta$ 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, $\overline{Y}$, 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 (assuming an interior solution and $\overline{K}_{Z,S} = 1$) corresponding to this optimization problem imply the following about the household-economy labor allocation and consumption:

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

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

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

The shadow value of home-cooked food emerges from these conditions ($\frac{\mu}{\lambda}$); 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. Condition 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. Eq. (3) demonstrates that the value of the marginal product of labor collecting
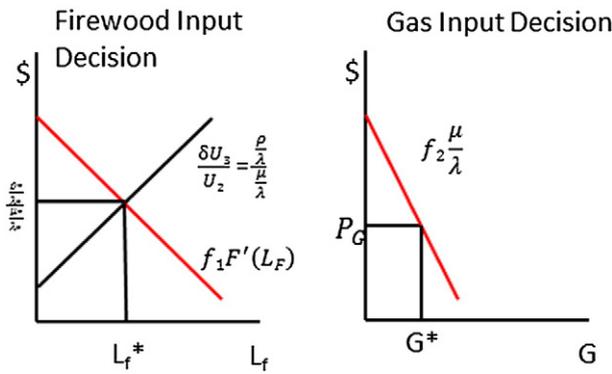
Firewood Input Decision

Gas Input Decision

Fig. 1. Household-specific equilibrium fuel choices.

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.[1] 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.

Fig. 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 the amount of gas purchased. The left graph in Fig. 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.

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. We 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 and fuel options are substitutable.[2] 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.

3.2. 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:

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

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 $\overline{z}^1$, 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

$$\min_{L_F, G} \frac{\rho}{\lambda} L_F + P_G G \; s.t.$$
$$z = f\big[F(L_F, \overline{R}_F, \overline{K}_F), G, L_Z, \overline{K}_Z, v\big] = \overline{z}^1$$

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

[2] Not modeled here is the case where foods produced from different fuel types are not perfectly substitutable. If the marginal utility of food cooked with wood goes to infinity as wood use approaches zero, the fuel ladder result cannot occur.

where $\bar{z}^1$ comes from the optimization problem presented above, as does the shadow value of labor. This decision in the full model produces an optimized value of utility, U_t^1.

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

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

which gives U_t^0. 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., $U_t^1 \geq U_t^0$). Obtaining the stove implies decreasing current period utility and requires an amount of 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,

$$s = 1 \text{ if } U_0(I(\overline{L}, D(\delta), \boldsymbol{Y}) - r) + \sum_1^T \frac{U_t^1}{(1+\varphi)^t} > U_0(I(\overline{L}, D(\delta), \boldsymbol{Y})) + \sum_1^T \frac{U_t^0}{(1+\varphi)^t}$$

$$s = 0 \text{ otherwise}.$$

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.

4. Data

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.[3] 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 villages with between 50 and 2499 people. Originally, the sample came from 80 villages 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, we 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.

4.1. 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 (74% 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 2 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. From this point forward, we only use observations from 2002 and 2007. The econometric analysis focuses on households that collect firewood.

Table 2
Proportion of HHs that collect firewood.

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

Relatively few households transition from collectors to non-collectors. Table 3 reveals that 46% collected in both years, 28% did not collect either year, and only 13% stopped collecting. Interestingly, some households that did not collect firewood in 2002 began collecting in 2007. Approximately three percent of households buy all of their firewood and do not collect it themselves.

Table 4 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 and this difference exists in 2002 and 2007. Between 2002 and 2007, there was an increase in remittances for all households with migrants. Importantly, households with no US migrant spend significantly more days collecting firewood than those with a migrant in the US.

Table 4 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 4 person-hours collecting.

Table 1 in the introduction 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.

Consistent with the empirical 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.

5. 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. We use 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. We 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, we assume the stove investment decision has already taken place and only include households with a gas stove. We then estimate a two-stage model, in which an investment decision precedes the labor allocation decision. Throughout this analysis we cluster standard errors at the village level.

Table 3
How constant is firewood collection? Proportion of households in each category

		2007	
		Collector	Non-collector[a]
2002	Collector	0.28	0.13
	Non-collector	0.13	0.46

[a] Includes households that left the panel in 2007.

Table 4
Firewood collection, remittances, and income (averages).

	2002	2007
Remittances if receive	23215	29993
Remittances if collect firewood and receive	23293	29157
Proportion of HHs with remittances	0.14	0.20
Proportion of firewood collectors with remittances	0.14	0.21
Average days collecting with no US migrant	107.37	96.88
Average days collecting with US migrant	74.49	74.38
Total income	40547	42973
Total income for firewood collectors	31460	38875
Household size	4.86	5.05
Number of days conditional on collecting	115.21	123.34
Person-hours per day of collection	(.)[a]	3.95

All values are in constant 2002 pesos.
[a] Not asked in 2002.

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. We use historical migration networks as instruments for current migration. Hausman tests indicate that, using networks as an instrument, the migration decision is endogenous to firewood collection decisions. Furthermore, networks pass the test of over-identifying restrictions using multiple network variables (parent in the US and Bracero program dummies). Finally, we demonstrate that our results are robust to multiple specifications and thus offer strong suggestive evidence regarding the causal impact of migration on fuel choice.

Conceptually, we consider this a necessary but imperfect identification strategy, because even though our network variables pass the standard tests for good instruments, are predetermined, and are substantially separated in time from current migration, in theory past migration could have provided remittances that influenced gas stove-investment decisions years prior to our study. Random assignment to migration would solve the selection problem; however, experimental solutions to migration identification obviously are problematic. McKenzie et al. (2010) exploited a unique feature of the New Zealand immigration system, in which visas are granted by a lottery, to obtain quasi-experimental estimates of migration impacts in the Tonga Islands, a migrant-sending country. That study is useful in demonstrating how an exogenous assignment of migration outcomes can be achieved in the real world, but its uniqueness testifies to how rarely migration policies create such research opportunities. Random assignment does not apply to Mexico-to-U.S. migration. The US has a lottery for immigration (Diversity Visa Green Card Program) from underrepresented countries; however, Mexicans are not eligible for it, and the vast majority of migration from rural Mexico to the US is unauthorized.

Lacking possibilities for randomization, migration research almost universally relies on IV methods. Munshi (2003) used weather as an instrument for migration. This would not be appropriate in our case, because weather is also likely to be correlated with local production activities, including natural resource use. Yang (2008) exploited the Asian financial crisis in his study of remittance impacts in the Philippines. The crisis provided a source of exogenous variation in exchange rates, which in turn were used as instruments for migrant remittances; Philippine migrants, even from the same households, went to different Asian countries prior to the crisis and thus experienced different exogenous shocks. The period of our data does not coincide with a major financial crisis, and virtually all migrants from rural Mexico go to the United States. Woodruff and Zenteno (2007) construct a migration instrument based on the completion of Mexican rail lines in the early 1900s. They posited that rail lines correlated with the reach of the Bracero Program, through which Mexicans could legally work in the United States between

1942 and 1964. Under this assumption, the Woodruff–Zenteno instrument is similar to one of the network instruments (*Bracero*) that we use, an indicator of whether villages were included in the Bracero program prior to 1964.

5.1. US Migration and Fuel Use for Households with Gas Stoves

The US migration decision and associated remittances potentially alter fuel mix only in households that own a gas stove. For these households, fuel use decisions entail how much of each fuel to use. We begin by taking investment in gas stoves as given and estimating the impact of migration on firewood collection for households that use both gas and firewood. The reduced-form model of the impact of migration on firewood collection takes the following form:

$$LnDays_{i,t} = \alpha + \beta Migrate_{i,t} + X_{i,t}\gamma + \varepsilon_{i,t}, \tag{1}$$

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, β (when multiplied by 100) represents the percentage impact of the 1–0 migration decision on days of firewood collection effort. $X_{i,t}$ controls for other household characteristics, which include the median village wage, household size, total income, ethnicity (a dummy variable indicating whether (1) or not (0) a household head speaks an indigenous language), and schooling (the number of adults with no higher than primary education). Income is potentially endogenous and is included as a robustness check. Regressions also include a year indicator to control for year-specific factors that affect all of rural Mexico in a given year such as energy prices. This also controls for potential changes in migration patterns over the 5-year period of the panel.

Here, $E(X_i\varepsilon_i) \neq 0$, because people may migrate because of a lack of abundant resources in an area or because of unobserved variables that influence both migration and resource use. Two-stage least-squares, with proper instruments, can enable us to identify the true impact of migration on firewood collection.

Migration networks instrument for household migration through their impact on a (the cost of migration) in 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 indicating whether or not the father of the household head migrated to the US at some time in the past. If the father of a household head worked in the US, he likely established a network there. In addition, Taylor and Lopez-Feldman (2009) use an indicator variable equal to 1 if a household is in a village that participated in the *Bracero* program and 0 otherwise. This program was available to some villages and not others, and while it may not have been exactly random (it followed the railroad in many cases; see Woodruff and Zenteno, 2007), it provides an improvement over treating migration as exogenous. A village that participated in the *Bracero* program is more likely to have established networks in the United States. Conceptually, the *Bracero* variable may hold an advantage over the first migration instrument, because it measures something that is more separate from the household in terms of both space (because it is at the village, not the household, level) and time (because the *Bracero* program ended in 1964, which predates the time period in which fathers of young household heads may have migrated). Therefore, the *Bracero* indicator is the preferred instrument. As we shall see below, our econometric findings are robust to a variety of model specifications.

The first stage (migration) regression is:

$$Migrate_{i,t} = \theta + Z_i\gamma + X_{i,t}\vartheta + u_{i,t},\tag{2}$$

where Z could be a dummy variable indicating whether or not the household is in a *Bracero* village 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:

$$LnDays_{i,t} = \alpha^{IV} + \beta^{IV}\widehat{Migrate}_{i,t} + X_{i,t}\gamma^{IV} + \varepsilon_{i,t}.\tag{3}$$

Finally, as a placebo test, we 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. Therefore reductions in firewood use translate into lower energy use. After controlling for changes in household size, there should be no impact of migration on firewood collection (assuming migrants' energy needs do not differ systematically from those of non-migrants).

Our strategy is designed to identify the marginal impact of migration on rural fuel use. It does not identify the impact of other, potentially endogenous household characteristics such as income. These characteristics enter the regressions as controls and do not affect the estimate of the impact of migration.

This identification strategy is repeated using monthly 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.

5.2. Identification Concerns

Our base identification strategy using instrumental variables requires that the instrument for migration be uncorrelated with the error term in Eq. (1) (the exclusion restriction). Two main possibilities exist that could violate this assumption, and we use multiple specifications to explore the robustness of our results to possible violations. First, if household stove adoption depends on village-specific factors that are correlated with participation in the Bracero program, it could be some other village level difference that drives the differences in fuel use. Below, we include several village-level variables (e.g., rates of stove use and importance of agriculture) to control for these possibilities. We also account for potentially endogenous stove ownership. Second, if *Bracero* villages differed along other dimensions when selected, the instrument may not satisfy the exclusion restriction. Overall, because the selection of *Bracero* villages was quasi-random (Taylor and Lopez-Feldman, 2009), selected villages should not have differed systematically from other villages.

5.3. 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:

$$Prob(have\ a\ gas\ stove)_{i,t} = \alpha + \beta^{IV}\widehat{Migrate}_{i,t} + X_{i,t}\gamma + \varepsilon_{i,t},\tag{4}$$

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.

We find that migration affects the probability of having a stove. This violates our initial assumption that having a stove is exogenous and so we use a Heckman selection approach to control for the potential endogeneity of stove ownership. This procedure controls for the fact that we only observe gas expenditures for households that invest in a gas stove. If results are robust to this specification, it suggests that the stove purchase decision does not significantly bias the results.

A Heckman selection model makes use of the first-stage 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:

$$Lngas_{i,t}^{*} = \alpha + \beta\widehat{Migrate}_{i,t} + X_{i,t}\gamma + \rho\sigma_\varepsilon\lambda\left(W_{i,t}\theta\right) + u_{i,t},\tag{5}$$

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 village adoption rates. θ are the parameters from the first stage. ρ is the correlation between $u_{i,t}$ and $\varepsilon_{i,t}$ and σ_us 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, we instrument for the migration decision.

5.4. Internal Migration

Finally, to test whether migration within Mexico has a similar effect, we repeat the estimation using internal (within-Mexico) migration. To instrument for within-Mexico migration, we use a variable equal to one if a household head's parent migrated within Mexico, zero otherwise.

6. Econometric Results

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 that collect firewood and have a gas stove. A variety of model specifications are presented to demonstrate robustness.

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. Both reveal a significant negative relationship between migration and firewood collection. The OLS result, significant at the 5% level, suggests that having a migrant in the United States reduces the number of days per year collecting firewood by around 25%. The IV result, also significant at the 5% level, requires further interpretation. While the endogenous migration indicator takes on the value of zero or one, the instrumental variables procedure uses predicted migration from estimation of equation two. This variable ranges from -0.14 to 0.81 with a mean of 0.26. and does not change discretely from zero to one. For example, residing in a Bracero community increases the predicted migration variable by 0.12. The estimated IV coefficient on migration (−3.339) means that a

Table 5
Impact of US migration on days collecting firewood.

VARIABLES	OLS	IV	RE	IV Placebo
LHS: days per year collecting firewood (log)				
US migrant	−0.249**	−3.339**	−0.244**	−7.524
	(−2.457)	(−2.047)	(−2.422)	(−0.806)
Wage (log)	−0.854***	−0.639	−0.836***	0.365
	(−3.408)	(−1.426)	(−3.381)	(0.299)
HH size (log)	0.214**	−0.426	0.217**	−0.333
	(2.422)	(−1175)	(2.483)	(−0.457)
HH income (log)	−0.00863	0.145	−0.00578	0.327
	(−0.209)	(1.656)	(−0.139)	(0.979)
Indigenous	−0.0120	−0.350	0.00173	−0.488
	(−0.0623)	(−1.071)	(0.00892)	(−0.431)
Only primary school	0.0307**	0.163**	0.0303**	0.233
	(2.082)	(2.104)	(2.030)	(0.836)
Year	0.379***	0.562***	0.371***	0.784
	(3.062)	(2.966)	(2.975)	(0.828)
Constant	6.550***	5.209**	6.452***	−0.554
	(5.742)	(2.638)	(5.743)	(−0.0768)
Observations	841	837	841	677
R-squared	0.065			

Standard errors clustered at the village level. t-stats presented in parenthesis.
*** p < 0.01.
 ** p < 0.05.

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

VARIABLES	(1)	(2)
	Monthly gas expenditure (ln)	Wood expenditure (ln)
US Migrant	1.609***	0.318
	(3.050)	(0.349)
Wage (Log)	−0.0868	0.0204
	(−0.551)	(0.0502)
HH size (Log)	0.354***	−0.0722
	(3.598)	(−0.545)
Rate of stove use	4.364***	0.184
	(20.49)	(0.367)
HH income (log)	0.0957***	0.0147
	(3.194)	(0.406)
Indigenous	−0.267	0.405
	(−1.443)	(1.419)
Only primary school	−0.126***	0.00409
	(−4.566)	(0.103)
Year	−0.0247	−0.124
	(−0.250)	(−0.694)
Constant	−0.518	0.393
	(−0.686)	(0.306)
Observations	2793	2793
R-squared	0.491	0.002

Standard errors clustered at the village level. t-stats presented in parenthesis.
*** p < 0.01.

household in a Bracero village spends an expected 40.07% fewer days collecting firewood.[4] This result does not change with the omission of household income on the RHS.

The results of a random effects model (Column 3), presented as a robustness check, are qualitatively similar, though more in the range of a 25% decrease in the number of days collecting firewood.[5] Finally, the impact of migration on firewood collection in households with no gas stove is presented as a placebo in Column 4. As expected, without a stove, migration (along with the other factors) does not significantly alter firewood collection. These results are robust to the inclusion of village level controls to account for potential observable village differences created by past migration.

Table 6 presents the results of the IV model showing the causal impacts of migration on gas and firewood purchases for all households (results are qualitatively similar using the sub-sample presented in Table 5).[6] Migration increases expenditure on gas by around 160%[7], while having an insignificant impact on firewood purchases. In combination, the results show 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.

In order to test whether migration pushes households up the "energy ladder" or only alters marginal decisions, we test the effect that migration has on the probability that a household collects firewood (Table 7). Consistent with the fuel-stacking hypothesis, sending a migrant to the United States does not significantly change the probability that a household collects firewood. Migration appears to cause households that use both firewood and gas to change their fuel use on the margin, but not to transition completely away from firewood collection.

6.1. 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 8 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 24%. The average effect of migration implied by the Probit with an endogenous RHS variable is 29%, not significantly different from the IV estimate. Because it does not differ qualitatively from the IV results, we 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.

6.2. Heckman Selection Model

Table 9 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 households choose whether or not to invest in a gas stove; gas expenditures are conditional upon this investment. Rho and sigma both

Table 7
Migration and use of firewood.

Variables	(1)	(2)	(3)
LHS: indicator = 1 if collect wood	Linear probability	Linear probability IV	Probit
US migrant	0.0300	0.278	0.0800
	(0.962)	(1.085)	(0.975)
Wage (log)	−0.103	−0.113	−0.276
	(−0.924)	(−1.136)	(−0.932)
HH size (log)	0.0880***	0.125**	0.234***
	(3.398)	(2.543)	(3.305)
HH income (log)	−0.0116	−0.0162	0.333***
	(−1.156)	(−1.405)	(3.504)
Indigenous	0.0675	0.105	−0.0312
	(0.692)	(1.020)	(−1.174)
Only primary school	0.0192***	0.00830	0.170
	(3.241)	(0.590)	(0.673)
Year	0.126***	0.0976**	0.0501***
	(3.627)	(2.096)	(3.231)
Constant	0.594	0.639	0.277
	(1.259)	(1.468)	(0.222)
Observations	1993	1981	1993
R-squared	0.042		

Standard errors clustered at the village level. t-stats presented in parenthesis.
*** p < 0.01.
 ** p < 0.05.

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[4] Average days collecting for firewood collectors that have a gas stove.
[5] There is insufficient variation in the within-household migration decision to identify a panel fixed-effects model.
[6] The larger sample is presented here for comparison with Table 9.
[7] Considering that the migration variable is predicted migration from the first-stage regression, the coefficient on migration implies that a household in a Bracero village increases expenditure on gas by 20%.

Table 8
Migration and gas stove investment.

t-Stats in parenthesis	(1)	(2)
Variables	IV Linear probability	Probit average effects
US migrant	0.237***	0.292***
	(2.892)	(4.194)
Rate of community stove use	0.891***	3.261***
	(29.41)	(26.69)
HH income (log)	0.0184***	0.108***
	(3.054)	(3.595)
Indigenous	−0.0186	−0.142
	(−0.627)	(−1.270)
Only primary school	−0.0192***	−0.0745***
	(−4.654)	(−6.356)
Year	−0.00470	0.0738
	(−0.283)	(1161)
Constant	−0.0860	−2.527***
	(−1.214)	(−7.582)
Observations	3056	3070
R-squared	0.483	

Standard errors clustered at the village level. t-stats presented in parenthesis.
*** $p < 0.01$.

Table 9
Heckman selection and Tobit estimation.

LHS: monthly gas expenditure	Heckman selection	Heckman selection with IV	Tobit
US migrant	0.172***	2.505***	0.746***
	(3.276)	(3.066)	(4.608)
Wage (log)	0.141	0.188	1.911***
	(1.233)	(0.662)	(2.741)
HH size (log)	0.240***	0.509***	0.158
	(3.518)	(3.763)	(1.399)
HH income (log)	0.0500*	0.0239	0.336***
	(1.776)	(0.648)	(4.522)
Indigenous	−0.384	−0.201	−3.272***
	(−1.241)	(−0.910)	(−6.141)
Only primary school	−0.0286***	−0.121***	−0.151***
	(−2.662)	(−2.653)	(−4.936)
Year	−0.0256	−0.314**	−0.265
	(−0.458)	(−2.403)	(−1.612)
Inverse-Mills ratio		−1.805***	
		(−9.883)	
Constant	3.586***	3.102**	−7.238**
	(5.612)	(2.366)	(−2.281)
Rho	−0.700**		
s.e.	(−2.296)		
Sigma	0.0651		
s.e.	(1.294)		
Lambda	3.112***		
s.e.	(12.14)		
Observations	2849	2793	2805

Standard errors clustered at the village level. t-stats presented in parenthesis.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

differ significantly from zero, indicating the presence of self-selection. In this case, ordinary least squares 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 250% 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 but qualitatively it appears that the potential endogeneity of stove adoption does not significantly impact results. 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 10 shows that having a migrant within Mexico does not necessarily reduce dependence on firewood collection for energy. 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.

7. Discussion

The results presented in this paper suggest that migration has facilitated an increase in the use 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 towards 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 used 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. 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 (Taylor, 1999; Yang, 2008).

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.

This finding means that migration from rural Mexico to the US has decreased reliance on local natural resources for energy. In areas where forests are badly managed, this could have important environmental implications as lower demand for firewood puts less pressure on often overexploited natural systems. Higher steady state resource stocks result as labor leaves the resource sector. In rural Mexico, there is substantial variation in the ability of villages to manage common forests. Areas that successfully manage forests may not see a large gain from a transition to gas. Villages where firewood sources have been depleted could benefit from this transition. Further research is needed to determine the circumstances under which reduced use of a common resource represents a substantial gain. Ostrom (1990) investigates the factors that lead to successful management of common resources and may provide insights into which villages could most benefit from reduced firewood demand.

Migration may allow villages with overused forest resources to more effectively reduce the amount of resources collected. As households have greater access to substitutes, they are more likely to accept some limitations on the amount or location of firewood they can collect.

Another implication includes the importance of resource protection once demand for the resource diminishes. As households depend less on local forests, the value of the land in forest may decrease, leading to potential land-use change. These impacts likely differ depending on the nature of forest property rights. According to the ENHRUM, in 2007, 53% of households collected firewood from common property (including communal, government, and *ejido* lands). The remaining collectors extracted firewood from private property forests. On private land, if owners no longer need firewood, conversion to agriculture (or some other use) may yield higher private value. On common property where decisions may require consensus among forest users, there may be more resistance to land-use changes.

Table 10
Within Mexico migration and firewood collection.

LHS variable: ln days collecting firewood	
Variables	IV
Internal migrant	2.268
	(1.233)
Wage (log)	−0.384
	(−0.828)
HH size (log)	0.599**
	(2.090)
HH income (log)	0.0226
	(0.374)
Indigenous	0.321
	(1617)
Only primary school	−0.0470
	(−0.851)
Year	−0.417
	(−0.719)
Constant	4.356*
	(1.958)
Observations	1514

Standard errors clustered at the village level t-stats presented in parenthesis..
** $p < 0.05$.
* $p < 0.1$.

One potential concern with our analysis is the mechanism through which migration reduces firewood collection.[8] Conversations with rural Mexican households indicate that firewood is often collected when returning from agricultural work. To explore this mechanism, we use an instrumental variables linear probability model and a Probit model and find an insignificant impact of migration on the likelihood of working in agriculture. We also include a dummy variable in the original analysis (Table 5) equal to 1 if a household supplies agricultural labor and find that it increases the time collecting firewood but does not change the impact of migration. Therefore, we conclude that migration impacts fuel use directly and not through a change in the sector of work. More in-depth case studies may provide better insight into the exact mechanisms driving the transition towards gas.

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 than internal migrants to send remittances home, and the average amount they remit is much higher. In 2007, fewer than two thirds of households with national migrants received remittances, while 85% of households with US migrants received remittances. National remittances averaged 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 between their destinations and households of origin might also play a role, 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 the migrants, themselves). Cash and the right incentives are required for households to invest in a gas stove and continually purchase gas. Our findings suggest that current urbanization trends in Mexico will have an effect on fuel use in rural villages only if it generates a sufficient flow of remittances into migrant-sending households. On the other hand, if the number of households in rural villages shrinks as a result of urbanization trends, overall wood use could go down without remittances.

Jones (2009) and Robson (2011) demonstrate that having a migrant does not guarantee the existence of remittances. They find that as a migrant spends more time away from home, the amount of money remitted begins to decline. For example, Robson (2011) found that in Oaxaca, adult children sent remittances of lesser amounts and/or reduced frequency. Therefore, households that send a migrant to the US may initially receive money to purchase gas but over time may find themselves with a lower labor supply yet no extra cash to purchase gas on a regular basis. Obtaining cooking energy then requires diverting scarcer labor time from other activities. Future work should explore these medium- and long-run impacts of migration on remittances sent and household labor supplies.

Other factors from this analysis that appear to influence fuel choice include the village median wage, household size, and whether a household is indigenous or not, though some of these factors are likely endogenous to firewood collection so results should not be over-interpreted. The correlation of household income and gas purchases is consistent with a loosening of liquidity constraints that facilitates investment in gas stoves and periodic purchase of gas. Higher village 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.

Interestingly, village gas stove adoption rates matter significantly for household adoption, which we control for in the econometric analysis. This could indicate that some advantages of gas are village specific or demonstration effects lead neighbors to increase their adoption of gas. For example, villages with easy access to forests may find it relatively cheap to continue using mostly firewood. On the other hand, villages lacking access to forests are more likely buy gas. Market scale also matters: gas must be transported to the village, and gas companies may be more willing to make trips to a village if more households are buying gas. The findings suggest that households anticipate this, and they increase their use of gas accordingly. This finding has the potential to bias estimates using the instrumental variables identification strategy because community level differences could correlate with participation in the *Bracero* program. To test robustness, we include stove adoption rates on the right-hand side of regressions presented in Tables 5 and 6. We also drop this variable from regressions presented in Table 8. The impact of migration on fuel use is not qualitatively affected by inclusion or omission of this variable (results available upon request).

The decision to migrate does not take place in isolation, and it is endogenous. The perfect experiment would involve randomized migration, which generally is not applicable in migration research. Weather shocks may be correlated with migration (e.g., De Silva, et al., 2010), but they are also likely to be correlated with natural resource activities and thus provide unconvincing instruments for our purposes.

In this paper we make an attempt to deal with migration endogeneity by using a variety of instrumental variable and panel methods, as is common in migration research. No instrument is perfect; however, all of our econometric strategies produce qualitatively similar results, suggesting that our findings are robust to model specification. Thus, we believe that our analysis is a useful step towards understanding the impacts of rural economic development in general and migration in particular on the use of natural resources and adoption of modern fuels.

8. Conclusion

When a household gains access to a new fuel it does not stop using traditional fuels. A complete switch to a new fuel represents a corner

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[8] We would like to thank an anonymous reviewer for pointing this out.

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 cost 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%, most of which consisted of whole-household migration (Arslan and Taylor, 2012).

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 influence 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 to integrate gas into the fuel mix. The framework presented in this paper, we 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.

Acknowledgments

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