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Electricity price hikes raise firewood consumption and women's collection time in Malawi

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Abstract

Carbon pricing has been proposed as an efficient instrument to reduce carbon emissions and curb climate change. However, in low-income countries, resulting high energy prices might induce trade-offs with other sustainable development goals, such as public health (resulting from increased firewood consumption) and gender equality. We develop a theoretical model to analyse the effect of rising fossil fuel prices on firewood consumption, and time use across fuel collection and labour supply. Given that the majority of firewood consumed in sub-Saharan Africa is collected by women, we also analyse the role of women's intra-household bargaining power in determining firewood consumption when energy prices rise. We test our model empirically, drawing on household- and individual-level panel data for Malawi for the 2010–20 period. We find a positive association between electricity price hikes and firewood consumption, with sizeable increases in women's and girls' time spent on firewood collection. Improved decision-making power for women is associated with a reduced likelihood of firewood use in the context of rising energy prices. Provision of cash transfers to households could alleviate the negative effects of energy price hikes. Targeted cash transfers could improve gender parity in decision-making and could partially mitigate biomass usage, potentially conferring substantial health and environmental benefits in low-income countries.

1. Introduction

Carbon prices have been posited as effective tools to reduce greenhouse gas emissions globally (Döbbeling-Hildebrandt *et al* 2024). While the majority of energy consumed in Malawi is drawn from biomass, a small but sizeable share of electricity generation is through diesel-based generators, with the government planning to expand on thermal-based power stations in the coming years (World Bank Group 2022). A carbon price on fossil fuels would likely raise the electricity prices faced by households in Malawi.

Despite the expected benefits from carbon prices, there are concerns that high relative prices for fossil-based fuels may push people down the energy ladder (Greve and Lay 2023) and increase the demand for biomass for cooking in sub-Saharan Africa (SSA) (Olabisi *et al* 2019, Alem and Demeke 2020). The prolonged use of biomass for cooking has adverse health effects via indoor air pollution (Roth *et al* 2018, Pratiti *et al* 2020) and results in forest degradation, especially in SSA (Masera *et al* 2015). Yet over 80% of the urban African population depends on charcoal for energy (Rose *et al* 2022), while close to 80% of the Malawian population relies on firewood for cooking (National Statistical Office of Malawi 2020). In this paper, we investigate the potential impacts of electricity price hikes on firewood consumption and fuel collection time among Malawian households.

Firewood collection in SSA is highly gendered in nature, with the burden falling disproportionately on women and children (Köhlin *et al* 2011). Significant disparities exist between women and men in their time

spent on cooking-related activities, including fuel collection across developing SSA and Asia (Krishnapriya *et al* 2021). Consumption of informal solid fuels, however, depends on the availability of household labour, particularly women's time, for collection (Bošković *et al* 2023). Thus, women's decision-making power within homes may be a key determinant of firewood consumption in low-income contexts. In Malawi, the majority of firewood used by households is obtained for free from local forests, rather than purchased in markets (National Statistical Office of Malawi 2020). These intra-household and labour market aspects of household energy use remain under-examined in the existing literature.

Recent works have modelled the effect of intra-household bargaining power on decisions to invest in sanitation infrastructure (Augsburg *et al* 2023) and the role of stated preferences in the use of improved biomass cookstoves in India (Jeuland *et al* 2020). Our study models household consumption and production decisions for a key energy source, firewood, using a non-separable framework. Furthermore, our model of firewood use can be applied to diverse contexts, such as water collection and consumption of other public goods within households.

Access to cleaner fuels like electricity can reduce the demand for kerosene and firewood (Dendup 2022) and can facilitate women's participation in the labour market by freeing up time from home production activities, as demonstrated in South Africa (Dinkelman 2011). Information provision on the adverse health effects of biomass burning can lead to an increase in the use of cleaner fuels and reduced indoor air pollution (for example, in India, information provision by public health workers on the benefits of clean fuel use led to a sizeable increase in regular use of liquefied petroleum gas (LPG) (Afridi *et al* 2021). Interventions to provide higher-quality and reliable water, sanitation and hygiene services can additionally provide significant health benefits and time savings, especially for women, who typically engage in water collection for the household (Chandrasekaran *et al* 2022). Access to improved cookstoves can also generate local health and environmental benefits, as well as global climate benefits (Pattanayak *et al* 2019).

While these studies evaluate important interactions between energy use, gender, health and individuals' time allocation, the role of female bargaining power in determining a household's optimal fuel choice is understudied in the literature. Recent work by Augsburg *et al* (2023) highlights the salience of women's bargaining power in optimal investment decisions regarding sanitation infrastructure in India. We contribute to the literature and develop a theoretical framework to highlight the salience of intra-household dynamics in decisions regarding energy consumption.

To theorise the role of bargaining power and the inter-linkages between energy prices and labour supply, we develop a collective household model, following the seminal works of Chiappori (1992) and Browning and Chiappori (1998). We model households' decisions regarding optimal firewood use as a function of men's and women's preferences for consumption of firewood versus other marketed fuels, labour versus leisure and women's 'bargaining weight' relative to men's 'bargaining weight' in the household. Since the majority of firewood for domestic consumption is collected rather than purchased, we model the collection and domestic consumption of firewood in a joint framework. Hence, in our model, households only collect fuelwood for domestic consumption, rather than to sell on the market (Zulu *et al* 2024).

Next, we empirically assess the effect of energy prices on firewood consumption among households' and individuals' time use for formal market work, informal market work (casual labour) and fuel collection for four demographic groups: men, women, boys and girls. We use several rounds of household- and individual-level panel data from the Malawi Integrated Household Panel Surveys (IHPS) over the 2010–20 period, which were conducted jointly by the National Statistical Office of Malawi and the World Bank's Living Standards Measurement Study (LSMS). Finally, we investigate the role of female intra-household bargaining power in determining whether households use firewood for cooking, relative to other marketed cooking fuels, in the context of rising electricity prices. Here, we construct a pooled cross-section of household-level data and woman-level data from the Malawi Demographic and Health Surveys (DHS) for the 2004–16 period. These surveys record information on a number of household decisions taken by various household members and the primary fuel for cooking in the household. We generate variables to capture women's 'bargaining power' as the number of decisions taken by women independently and those taken jointly with their husbands, following the literature (Annan *et al* 2021, Jayachandran *et al* 2023).

The results show a positive association between electricity prices and firewood consumption in Malawi, with a 1% increase in electricity prices, raising annual firewood consumption by 2.6% and by up to 4.3% in urban areas. Energy price hikes have consequent effects on the labour market as individuals reallocate their time from paid market work towards firewood collection, in response to higher electricity prices. These effects are especially pronounced for women and girls, while they are rather muted for men and boys. Higher electricity prices are also negatively associated with children's literacy.

Women's bargaining power plays an important role in determining a household's use of firewood for cooking purposes. Women's autonomy in household decision-making is associated with a lower likelihood of firewood use in the context of rising electricity prices. Similarly, increases in household wealth simultaneous

to improvements in women's decision-making power are associated with a lower probability of a household using firewood for cooking. Furthermore, increases in household wealth simultaneous to increases in electricity prices and improvements in women's bargaining power are associated with a reduced likelihood of the household consuming firewood for cooking. These findings highlight the significant role of intra-household dynamics in shaping decisions regarding energy use.

The paper is outlined as follows. Section 2 briefly discusses the theoretical framework, data sources, descriptive statistics and estimation strategy. Section 3 presents the results, while section 4 discusses the model's assumptions, robustness checks and concludes the paper. The appendix presents detailed derivations of the theoretical model and additional descriptive statistics.

2. Methods and data

2.1. Conceptual framework

Consider a household with two types of members—men and women—as the decision makers. Households engage in firewood 'production' or collection following a home production technology, with their labour as inputs in the process. Firewood is modelled as a non-marketable commodity, where households collect and use firewood at home for cooking, lighting or heating purposes. Households maximise the weighted sum of women's and men's individual utilities, U_{f} and U_{m}, weighted by the respective 'bargaining' weights, ϕ and $(1-\phi)$. Individual weights are determined through a long-term cooperation process (Chiappori 1992).

The household maximises the weighted utility function:

$$\max_{\{M,F,l_{\mathrm{f}},l_{\mathrm{m}}\}} \quad \phi\, U_{\mathrm{f}}\left(M,F,l_{\mathrm{f}}\right)+\left(1-\phi\right) U_{\mathrm{m}}\left(M,F,l_{\mathrm{m}}\right) \tag{1}$$

subject to a household budget constraint:

$$P_{\mathrm{M}}M \leqslant y+w_{\mathrm{f}}\left(L_{\mathrm{f}}+L_{\mathrm{wf}}\right)+w_{\mathrm{m}}\left(L_{\mathrm{m}}+L_{\mathrm{wm}}\right). \tag{2}$$

Men and women derive utility from use of energy sources such as firewood (F), market energy sources (M) and private time spent on leisure. Private leisure time is the total time available for rest or entertainment after deducting time spent on market work and fuel collection from the total time available in a day. The household maximises utility subject to a household-level budget constraint, which reflects the prices of fossil-based market energy sources, the cost of firewood collection, women's bargaining weight, household income and other preference parameters.

This collective household model is solved recursively in two stages, following Chiappori and Ekeland (2009). In the first stage, individuals jointly decide on purchases of market energy sources and the amount of firewood consumption. In the second stage, each individual decides on their 'optimal' time spent on the labour market and the time remaining for leisure activities, taking the household's decision-making problem for other parameters as fixed. Solving the model generates a demand function for firewood and private labour supply.

The firewood demand function, $F=F(P_{\mathrm{M}},P_{\mathrm{F}},y,\phi)$, depends on the price of the fossil fuel (P_{M}), the household's income (y), women's bargaining weight (ϕ) and the cost of firewood collection P_{F} (which, in turn, depends on the market wage rates for men and women since an individual's time spent on firewood collection is valued at their market wages). Similar functions for individual labour supply are generated, which also depend on energy prices, household income and individual characteristics such as level of education. The detailed theoretical framework is presented in appendix A.2. In the next section, we empirically test the model by applying the firewood demand and labour supply functions to household- and individual-level data for Malawi. In the empirical application, we do not estimate women's bargaining weights. However, we apply data-driven proxies to measure women's bargaining power within the home.

2.2. Data sources

We use four rounds of household- and individual-level panel data between 2010 and 2020, drawn from the Malawi IHPS conducted by the National Statistical Office of Malawi, in partnership with the World Bank's LSMS programme. These survey rounds are 2010–11, 2013, 2016–17 and 2019–20. The surveys are nationally representative of the 28 districts of Malawi. We use household-level information on firewood consumption, total annual consumption expenditure (including spending on food, non-durable goods and durables), and geographic characteristics. Furthermore, we use information on individuals' time allocation between market work, informal labour and hours spent on firewood collection, and individual demographics such as age, gender and level of education.

The quantity of firewood consumed is constructed as the ratio of the recorded monetary value of firewood consumption (scaled to annual levels) and the reported price of firewood in the corresponding

district. While the majority of firewood that is consumed is collected for free from forests and unfarmed communities in Malawi, a small proportion of firewood is being purchased in markets (Jagger *et al* 2024). We merge the household-level consumption and time-use data with energy price data from a distinct cluster/enumeration area-level survey for fuel prices, based on the month and year of the survey. The cluster survey collects information on prices for kerosene, charcoal and firewood.

We also obtain data on average domestic electricity tariffs in Malawi at a monthly frequency for the corresponding time period from the Quarterly Statistical Bulletins published by the National Statistical Office of the Government of Malawi.

Time-use data for men, women and children, drawn from the Malawi IHPS, provide information on individuals' weekly hours worked for wage/salary and casual labour, and the hours spent the day preceding the survey in firewood collection. We construct weekly hours spent on firewood collection for all individuals to ensure comparability with labour supply variables.

Lastly, to assess the role of women's bargaining power in cooking fuel choice, we use the Malawi DHS for the years 2004–5, 2010 and 2015–16. We merge household-level data and woman-level data from the DHS with electricity price data by the year and month of the survey. This provides significant price variation to estimate the effects of electricity prices on cooking fuel choice and the mediating role of women's bargaining power.

We measure women's bargaining power on four metrics related to whether the woman makes decisions independently or jointly with her spouse regarding (i) large household purchases, (ii) visits to family and friends, (iii) accessing women's healthcare services and (iv) spending from her earnings. For each of these variables, we assign a score of '0' if the husband or someone else from the family independently makes decisions, a score of '0.5' if the woman and her spouse jointly make decisions and a score of '1' if the woman independently makes decisions in each of these domains. Women's bargaining power is then measured as the sum of the scores assigned to each of these four metrics. A higher score indicates more autonomy for women within the home.

To control for household wealth, we use the wealth index score available in the DHS survey, taking the inverse hyperbolic sine (IHS) transformation, which preserves negative values. The outcome is a dummy variable for whether or not the household uses wood as a cooking fuel.

2.3. Descriptive statistics

We present summary statistics on cooking fuel choice by rural/urban region for the latest year, 2019–20, in figure 1. We find that households largely consume firewood (collected) for cooking in rural areas. Nearly 90% of households consume either collected or purchased firewood in rural areas. The share of electricity consumption is low, at around 1% of the rural sample. On the other hand, in urban Malawi, a high share of residents consumes charcoal for cooking purposes, while close to 20% of the sample consumes firewood as well. Around 8% of the households also consume electricity for cooking.

Next, we present key energy consumption and price statistics for the latest survey year, 2019–20, in table 1. We compute the mean annual fuelwood consumption as a ratio of the reported annual monetary value of firewood consumed to the district-month average price of firewood, which is obtained from the cluster price survey. We observe a mean annual consumption of 717 heaps of fuelwood per household in 2019–20. Firewood prices exhibit a significant variation within the year, ranging from MK 30 to MK 1000, with a mean of approximately MK 200 per heap (approximately USD 0.10).

Electricity prices vary only at a monthly frequency within the year and hence exhibit sizeable variations over the year. Detailed electricity price statistics by survey year are presented in the appendix, table A2. The detailed table shows that electricity tariffs have risen from an average of MK 7 to MK 65 per kWh over the 2010–20 period. Additional household- and individual-level statistics are presented in appendix A.1.

2.4. Empirical strategy

We estimate regression models of firewood demand and individuals' labour supply in response to energy price increases while controlling for a range of household- and individual-specific characteristics.

2.4.1. Firewood consumption

We apply the ordinary least squares (OLS) with fixed effects estimator for firewood consumption, as follows:

$$Y_{it} = \alpha_i + \gamma_s + \beta P_{E_{mt}} + \omega P_{F_{mt,r}} + \delta X_{it} + \epsilon_{it} \tag{3}$$

where Y_{it} is the annual log quantity of firewood consumed by household i in year t. $P_{E_{mt}}$ is the log price of electricity in month m in year t. $P_{F_{mt,r}}$ is the log price of firewood in region r, month m and year t. Firewood

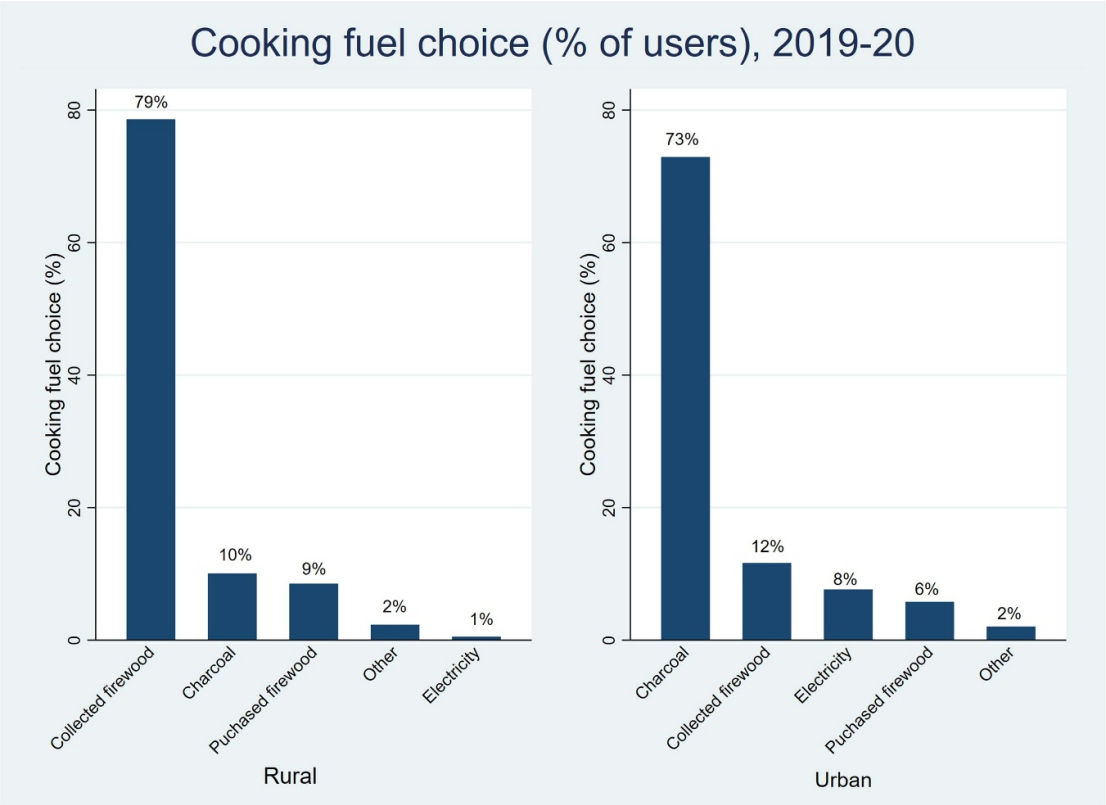

Figure 1. Cooking fuel choice (% of users), panel sample, 2019–20.

Table 1. Summary statistics, panel sample, 2019–20.

Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
Firewood consumption (heaps)	1839	717	825	0	10 759
Electricity price (MK kWh^{-1})	3178	65	.55	64	65
Firewood price (MK per heap)	2222	198	181	30	1000
Charcoal price (MK per 50 kg bag)	2222	2904	1083	1500	10 000
Household size	3178	4.6	2.2	1	20
Household Real expenditure (MK)	3178	171 678	231 937	598	3581 210

Note: Firewood consumption is measured annually per household. The survey data do not provide metric units of measurement for firewood use. A heap of firewood typically weighs around 25–30 kg.

prices are averages at the level of district, month and year. Where district prices are missing, these are imputed with the national average price for firewood by month and year. X_{it} is a vector of controls including the household size and the log of real total household expenditure[5]. The regressions include household-level fixed effects, α_i, and survey round fixed effects, γ_s.

The survey data for the 2016–17 round do not contain information on fuel prices. Hence, we omit this round in regression specifications that contain the price of firewood as an independent variable. However, we retain observations from this round for all other regressions.

For some specifications, we control for stratum fixed effects, which are interactions between the three Malawian regions (Northern, Central and Southern) and rural/urban areas. These control variables capture differences in access and distance to forests, which would likely correlate with firewood prices and influence baseline firewood consumption.

[5] Nominal total expenditure (which consists of expenditure on food, non-durables and durables) is deflated by the annual consumer price index, obtained from the World Bank Database.

2.4.2. Time use

We estimate the traditional random-effects tobit model for individuals' time allocation across paid work and fuel collection. This model accounts for self-selection into various labour market activities. The following equation is estimated for individuals participating in the labour market or in fuel collection:

$$Y_{it} = \alpha_i + \gamma_s + \beta P_{E_{mt}} + \omega P_{F_{mt,r}} + \delta X_{it} + \epsilon_{it} \tag{4}$$

where Y_{it} is one of three outcomes for individual i in year t: (i) log hours worked per week for wage/salary; (ii) log hours worked per week in casual labour; and (iii) log hours spent per week in firewood collection. Fuel prices are as defined above, while the vector of controls X_{it} additionally contains individual characteristics like age and level of education. We rely on the individual's level of education to capture important differences in individuals' productivity levels.

2.4.3. Role of decision-making parity

We estimate a probit model to explore the role of women's decision-making parity in a household's use of firewood for cooking in response to electricity prices:

$$Y^*_{it} = \gamma_0 + \gamma_1 P_{E_{mt}} + \gamma_2 B_{it} + \gamma_3 W_{it} + \gamma_4 P_{E_{mt}} \times B_{it} \times W_{it} + \delta X_{it} + \epsilon_{it} \tag{5}$$

with $Y_{it} = 1$ if $Y^*_{it} > 0$ and 0 otherwise. Y_{it} is a dummy variable for woman i in survey year t, which takes the value '1' if the household uses firewood as the main cooking fuel, and '0' otherwise. The covariates include the price of electricity $P_{E_{mt}}$ for month m and year t, women's bargaining power B_{it}, the IHS transformation of the household's wealth score, W_{it}, and a vector of control variables, X_{it}, including household size, the household's access to electricity and dummy variables for the year and stratum (region × rural/urban areas). In different specifications, the model includes pair-wise interactions between electricity prices, women's bargaining power and household wealth.

3. Results

We present regression results for the effects of energy prices on firewood consumption, individuals' time allocation across labour market activities, and the role of female bargaining power in determining firewood use.

3.1. Firewood use

We find electricity prices to be positively associated with the quantity of firewood consumed, controlling for various potential confounders, including the price of firewood, and household and survey round fixed effects (table 2). A 1% increase in the price of electricity raises the quantity of firewood consumed by 2.6%–3.8%. These effects are largely driven by urban areas, where firewood consumption rises by 4.3% on average in response to a 1% increase in electricity tariffs, whereas in rural areas, the effects are positive but not statistically significant. These effect sizes are substantial when compared to the existing literature on patterns of fuel substitution. These reduced form effects are similar to those found in studies on Uganda and Tanzania (Olabisi *et al* 2019, Aggarwal *et al* 2024).

In these regressions, we control for the market price of firewood, the household's real total consumption expenditure, household size and access to electricity. We also include household and survey round fixed effects, as well as stratum fixed effects in one specification to account for regional differences in proximity to forests and other regional confounders.

Contrary to the literature, we find household expenditure to be negatively associated with firewood consumption, and the effect is statistically significant at the 95% confidence level (Chakrabarti and Handa 2023). This suggests that firewood is an inferior good in households' consumption baskets, which has been confirmed in qualitative field studies in Malawi (Jagger *et al* 2024).

These patterns of fuel substitution suggest that a household's consumption of firewood for cooking increases as electricity becomes more costly, particularly in urban areas. The results also suggest a possible income effect as high electricity prices tend to reduce consumers' real income, and the reduction in real income may also spur a shift towards firewood consumption. Given that the majority of households are at or below subsistence consumption and over a quarter of the population is under-nourished (Global Hunger Index 2018), it is plausible that households reallocate budgets towards necessities such as fuel purchase for cooking and meal preparation when electricity prices rise.

Table 2. Effects of energy prices on firewood consumption, panel sample 2010–20, OLS with fixed effects.

Log(firewood quantity)	(1) All	(2) All	(3) Rural only	(4) Urban only
Log(electricity price)	3.754***	2.624***	1.029	4.324**
	(0.470)	(0.652)	(0.873)	(1.981)
Log(Household real expenditure)		−0.368***	−0.323***	−0.535**
		(0.064)	(0.081)	(0.251)
Household size		0.196***	0.181***	0.356***
		(0.024)	(0.033)	(0.083)
Log(firewood price)		−1.093***	−1.201***	0.023
		(0.138)	(0.189)	(0.462)
Lack of access to electricity		0.981***	0.029	0.939**
		(0.185)	(0.355)	(0.430)
Observations	9293	6284	4525	1759
R^2	0.321	0.116	0.050	0.130
F	1727.05	44.07	13.77	7.72
Household Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
Region × rural/urban Fixed Effects	No	Yes	No	No

Robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Columns (2)–(4) omit the 2016–17 round due to lack of data on firewood prices.

Table 3. Effects of electricity prices on individuals' hours spent on casual labour per week, panel sample 2010–20 (random effects tobit estimator).

Log(hours—casual labour)	Model coefficients (1)	Average marginal effects (2)
Log(electricity price)		
Men	−0.529	−0.529
	(0.715)	(0.715)
Women	−0.970	−0.970
	(0.716)	(0.716)
Boys (<18 years)	−1.780**	−1.780**
	(0.717)	(0.717)
Girls (<18 years)	−1.914***	−1.914***
	(0.717)	(0.717)
Log(firewood price)	0.018	0.018
	(0.105)	(0.105)
Log(Household real expenditure)	−0.818***	−0.818***
	(0.059)	(0.059)
Age	−0.017***	−0.017***
	(0.004)	(0.004)
Level of education		
Secondary school	−0.726***	−0.726***
	(0.143)	(0.143)
High school	−1.287***	−1.287***
	(0.211)	(0.211)
College graduate & above	−2.184***	−2.184***
	(0.418)	(0.418)
Observations	24 793	24 793
Chi-squared Statistic	1393.25	1393.25

Asymptotic standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The reference category for education is 'none'. The regression includes dummy variables for the survey round and stratum (region × rural/urban dummy).

3.2. Time allocation

Energy price increases have consequent labour market effects, particularly for informal work. Our results suggest that high electricity prices reduce an individual's time spent in casual work and salaried work (table 3). While the effects are not statistically significant for adults, we find statistically significant declines in child labour for both boys and girls (defined as individuals less than 18 years of age) (table 4). Specifically, a

Table 4. Effects of electricity prices on individuals' hours spent on wage/salaried work per week, panel sample 2010–20 (random effects tobit estimator).

Log(hours—wage/salaried work)	Model coefficients (1)	Average marginal effects (2)
Log(electricity price)		
Men	0.649	0.649
	(0.988)	(0.988)
Women	−0.297	−0.297
	(0.988)	(0.988)
Boys (<18 years)	−1.756*	−1.756*
	(0.998)	(0.998)
Girls (<18 years)	−1.994**	−1.994**
	(1.000)	(1.000)
Log(firewood price)	0.237	0.237
	(0.178)	(0.178)
Log(Household real expenditure)	0.727***	0.727***
	(0.094)	(0.094)
Age	0.052***	0.052***
	(0.006)	(0.006)
Level of education		
Secondary school	1.293***	1.293***
	(0.204)	(0.204)
High school	3.114***	3.114***
	(0.240)	(0.240)
College graduate & above	4.233***	4.233***
	(0.332)	(0.332)
Observations	24 793	24 793
Chi-squared Statistic	1257.07	1257.07

Asymptotic standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The reference category for education is 'none'. The regression includes dummy variables for the survey round and stratum (region × rural/urban dummy).

1% increase in electricity prices reduces the weekly hours spent in both formal and informal work by up to 2% for boys and girls.

We find that increases in electricity prices lead to shifts away from paid market work towards firewood collection, but only for women and girls (table 5). A 1% increase in electricity prices increases the weekly hours spent on firewood collection by 0.8% for girls and 1.5% for women. However, we do not find any statistically significant effects on men's and boys' time spent on firewood collection in response to electricity price hikes. All regressions of time use control for the individual's age and level of education, as well as the price of firewood, the household's total expenditure and other geographic controls.

Lastly, we find that electricity price increases are associated with reductions in children's literacy (table 6). A 1% increase in electricity prices is associated with a 44%–47% reduction in the likelihood of children being literate in any language. Given that these effects are largely correlational, more research is needed to disentangle the dynamics of schooling decisions within households in the context of rising energy prices. Since the household surveys do not record children's time spent in school, we are unable to investigate this channel directly.

3.3. Role of women's bargaining power

From the Malawi DHS household survey data (table 7), we find that higher electricity prices raise the likelihood of firewood use for cooking. Household wealth is also negatively associated with the likelihood of firewood use, which suggests that firewood may be an inferior good in Malawi. Similarly, we find that improvements in women's bargaining power reduce the likelihood of firewood use for cooking. Given multiple interaction effects, we only report the probit regression coefficients, but we do not report the average marginal effects[6]. Hence, these results may only be interpreted qualitatively.

The interaction effects of electricity prices and women's bargaining power, and those between the household wealth score and women's decision-making power, are negative and statistically significant at the 95% confidence level. These interaction effects suggest that increases in women's autonomy in

[6] Average marginal effects are not defined for multiple interactions.

Table 5. Effects of electricity prices on individuals' hours spent on firewood collection per day, panel sample 2010–20 (random effects tobit estimator).

Log(hours—firewood collection)	Model coefficients (1)	Average marginal effects (2)
Log(electricity price)		
Men	0.530	0.530
	(0.453)	(0.453)
Women	1.528***	1.528***
	(0.453)	(0.453)
Boys(<18 years)	0.347	0.347
	(0.454)	(0.454)
Girls (<18 years)	0.843*	0.843*
	(0.453)	(0.453)
Log(firewood price)	0.198**	0.198**
	(0.086)	(0.086)
Log(Household real expenditure)	−0.251***	−0.251***
	(0.042)	(0.042)
Age	−0.006**	−0.006**
	(0.003)	(0.003)
Level of education		
Secondary school	−0.549***	−0.549***
	(0.113)	(0.113)
High school	−1.350***	−1.350***
	(0.204)	(0.204)
College graduate & above	−2.910***	−2.910***
	(0.625)	(0.625)
Observations	24 793	24 793
Chi-squared Statistic	1536.48	1536.48

Asymptotic standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The reference category for education is 'none'. The regression includes dummy variables for the survey round and stratum (region × rural/urban dummy).

Table 6. Effects of electricity prices on children's literacy by gender, panel sample 2010–20, random-effects probit estimator.

Literacy (read text in any language)	Model coefficients (1)	Average marginal effects (2)
Log(Electricity price)		
Boys (<18 years)	−0.472***	−0.472***
	(0.163)	(0.163)
Girls (<18 years)	−0.436***	−0.436***
	(0.163)	(0.163)
Log(firewood price)	−0.053*	−0.053*
	(0.030)	(0.030)
Log(Household real expenditure)	0.192***	0.192***
	(0.016)	(0.016)
Lack of access to electricity	−0.394***	−0.394***
	(0.047)	(0.047)
Observations	10 359	10 359
Chi-squared Statistic	869.21	869.21

Asymptotic standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. The regression includes dummy variables for the survey round and stratum (region × rural/urban dummy).

decision-making, in the context of rising fuel prices, reduce the likelihood of firewood use for cooking. Similarly, wealthier households where women exhibit greater decision-making power are less likely to use firewood for cooking. Finally, we also find a statistically significant coefficient for the triple interaction term, although the effect size is rather small. This suggests that simultaneous increases in energy prices, women's decision-making power and household wealth can reduce the dependence on firewood use.

Given that we do not have panel data in the DHS, we find the results for this research question to be suggestive, rather than conclusive. This is an important aspect to be studied in future work, potentially with

Table 7. Effects of women's bargaining power on firewood use, DHS 2004–5 to 2015–16 (probit model).

Cooking fuel (wood = 1, other = 0)	(1)	(2)	(3)	(4)
Log(electricity price)	0.390**	0.407***	0.415***	0.392**
	(0.156)	(0.156)	(0.157)	(0.156)
IHS Household Wealth score	−0.048***	−0.048***	−0.044***	−0.046***
	(0.001)	(0.001)	(0.001)	(0.001)
Women's bargaining power	−0.051***	−0.003	0.015	−0.047***
	(0.009)	(0.026)	(0.027)	(0.010)
Household size	0.119***	0.120***	0.119***	0.119***
	(0.005)	(0.005)	(0.005)	(0.005)
Access to electricity	−0.705***	−0.706***	−0.706***	−0.704***
	(0.025)	(0.025)	(0.025)	(0.025)
Log(electricity price) × Women's bargaining power		−0.017*	−0.018**	
		(0.009)	(0.009)	
IHS Household Wealth score × Women's bargaining power			−0.004***	
			(0.001)	
Log(electricity price) × Women's bargaining power × IHS Household Wealth score				−0.000*
				(0.000)
Observations	47 598	47 598	47 598	47 598
Pseudo R^2	0.45	0.45	0.45	0.45

Robust standard errors in parentheses. * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.
Regressions include year and region × rural/urban control variables. We apply the inverse hyperbolic sine (IHS) transformation of the household's wealth score to retain low values of household wealth.

the use of experimental data to capture exogenous changes in women's bargaining power within the household (Attanasio and Lechene 2014).

4. Discussion and conclusion

We have developed a collective household model to analyse the effects of energy prices on firewood consumption and individuals' time use, exploring the role of women's bargaining power in fuelwood use. Our theoretical model predicts that increases in prices for fossil-based cooking energy (such as electricity generated from thermal sources) lead to increases in fuelwood consumption through substitution effects for cooking fuels. Next, the model predicts that increases in fuelwood consumption would consequently lead to increases in an individual's time spent on fuel collection.

We test the model empirically by estimating the effects of electricity price increases on household firewood consumption and individuals' labour supply and analyse the role of women's bargaining power in energy-use decisions. The empirical results validate the predictions of the theoretical model, and we find increases in firewood consumption in response to electricity price hikes, with concomitant shifts in individuals' time spent from market work towards fuelwood collection. However, contrary to the model, we only find time re-allocations for women and girls. Our results thus reinforce findings from the empirical literature on the gendered nature of fuelwood collection. In all regressions, we include several covariates to control for potential confounding factors and ensure the results are robust to different specifications. In particular, we account for regional variation in access to forests and firewood prices by including region and rural–urban fixed effects.

A limitation of our analysis of labour supply effects is the use of household expenditure in the labour supply regressions, rather than the use of individuals' non-labour income. While adult labour supply is a function of non-labour income, rather than household expenditure, which may be potentially endogenous to labour supply decisions, lack of available data on non-labour income or wealth precluded its use in the regressions.

Our results highlight an important role for women's bargaining power in the intra-household decision-making process as a determinant of biomass consumption, particularly given the highly gendered nature of firewood collection in Malawi and the broader SSA region. The results imply that, to effectively reduce emissions while promoting economic development, environmental policy design in developing countries will require improving women's bargaining power within the household, while ameliorating the adverse welfare effects of fossil fuel price increases.

An important implication for sustainable development policy is the provision of cash transfers, which could raise household wealth and assist households to climb the energy ladder through wealth effects and improvements in women's decision-making power. The appropriate design of cash-transfer schemes is highly debated in development policy. Lump-sum cash transfers from carbon pricing revenue could enable households to purchase clean cooking technologies. Cash transfers targeted to women could enable spending decisions that improve women's and children's welfare within homes. Alternatively, long-term empowerment for women could be enabled through sustainable employment programmes. The Government of India's National Rural Employment Guarantee Scheme provides an apt example of a targeted employment programme for women, which has resulted in high female workforce participation and women's empowerment. Cash transfers or employment support programmes for women in combination with emissions pricing could thus enable cleaner energy transitions in developing countries.

Data availability statement

The data that support the findings of this study are openly available at the following URL/DOI: https://github.com/raavi-aggarwal/Electricity--price-hikes-raise-firewood-consumption-and-women-s-collection-time-in-Malawi.

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Appendix

A.1. Descriptive statistics (extended)

In this section, we present descriptive statistics of a household's total real annual expenditure by survey round (table A1) and energy prices (table A2). Statistics on individuals' time allocation across (i) casual labour, (ii) formal labour and (iii) firewood collection for 2019–20 are presented in table A3, while statistics on individuals' level of education are presented in table A4. Statistics on households' choice of cooking and lighting fuels by rural and urban areas and survey round are presented in tables A5 and A6. Lastly, descriptive statistics of the percentage of decisions taken jointly by men and women vis-à-vis decisions taken independently by women are reported from the DHS data, 2015–16, in table A7.

Table A1. Annual household expenditure (MWK), panel sample 2010–20.

Year	Observations	Mean	Standard Deviation	Minimum	Maximum
2010–11	1619	140 314	218 468	0	6243 520
2013	1988	219 255	315 131	0	5052 463
2016–17	2507	195 140	257 128	1469	6339 436
2019–20	3178	171 678	231 937	598	3581 210
Total	9292	182 686	257 518	0	6339 436

Table A2. Summary statistics: energy prices, panel sample, 2010–20.

Electricity prices (MK kWh^{-1})	Mean	Standard Deviation	Minimum	Maximum
2010–11	6.6	0.74	6.2	8.5
2013	23	2.7	20	27
2016–17	49	3.3	45	58
2019–20	65	0.55	64	65
Charcoal prices (MK/50 kg bag)	Mean	Standard Deviation	Minimum	Maximum
2010–11	566	205	150	1500
2013	662	682	50	5100
2019–20	2904	1083	1500	10 000
Firewood prices (MK/heap)	Mean	Standard Deviation	Minimum	Maximum
2010–11	25	11	10	71
2013	67	38	25	300
2019–20	198	181	30	1000

Table A3. Hours spent per week in labour market activities, panel sample, 2019–20.

Casual labour	Observations	Mean	Standard Deviation	Minimum	Maximum
Men	3513	5.5	13	0	96
Women	3893	2.5	7.3	0	81
Boys	2440	0.97	4.7	0	70
Girls	2656	0.52	2.8	0	45
Total	12 502	2.6	8.4	0	96
Wage/salaried Job	Observations	Mean	Standard Deviation	Minimum	Maximum
Men	3513	5.9	16	0	144
Women	3893	1.7	8.5	0	84
Boys	2440	0.13	2.2	0	56
Girls	2656	0.05	1.6	0	72
Total	12 502	2.2	10	0	144
Fuelwood collection	Observations	Mean	Standard Deviation	Minimum	Maximum
Men	3514	0.3	1.9	0	49
Women	3893	2.6	5.9	0	84
Boys	2440	0.3	2.4	0	70
Girls	2656	1.0	4.1	0	70
Total	12 503	1.2	4.2	0	84

Note: The groups of individuals are categorised by age and sex: men (18+ years), women (18+ years), boys (0–18 years) and girls (0–18 years). The statistics exclude individuals who do not participate in the labour market (i.e. missing observations).

Table A4. Percentage distribution of individuals by level of education, panel sample, 2019–20.

Level of education	None	Secondary school	High school	Graduate & above	Total
Men	78.02	13.63	7.29	1.06	100.00
Women	80.14	11.96	6.82	1.08	100.00
Boys	68.28	19.70	11.26	0.76	100.00
Girls	67.69	20.28	11.60	0.43	100.00
Total	73.36	16.50	9.32	0.82	100.00

Table A5. Percentage distribution of fuel use for cooking (%), panel sample, 2010–20.

Rural sample						
Survey round	Collected firewood	Purchased firewood	Electricity	Charcoal	Other	Total
2010–11	87.76	8.83	0.79	2.10	0.51	100.00
2013	82.90	10.47	0.40	4.71	1.52	100.00
2016–17	76.24	11.89	0.61	7.94	3.32	100.00
2019–20	78.59	8.52	0.52	10.06	2.32	100.00
Urban sample						
Survey round	Collected firewood	Purchased firewood	Electricity	Charcoal	Other	Total
2010–11	21.25	22.49	12.32	43.32	0.63	100.00
2013	16.46	24.77	10.41	46.50	1.86	100.00
2016–17	9.91	15.23	6.39	67.25	1.22	100.00
2019–20	11.64	5.78	7.63	72.91	2.03	100.00

Table A6. Percentage distribution of fuel use for lighting (%), panel sample, 2010–20.

Rural sample						
Survey round	Firewood	Paraffin	Electricity	Battery/dry cell	Other	Total
2010–11	3.91	62.81	2.60	24.49	6.18	100.00
2013	3.91	12.76	3.32	73.13	6.87	100.00
2016–17	4.73	2.60	5.09	80.78	6.80	100.00
2019–20	4.57	0.46	7.14	83.47	4.36	100.00
Urban sample						
Survey round	Firewood	Paraffin	Electricity	Battery/dry cell	Other	Total
2010–11	0.45	53.94	28.61	6.17	10.83	100.00
2013	1.78	17.97	34.15	21.79	24.31	100.00
2016–17	0.43	2.21	45.24	29.36	22.76	100.00
2019–20	0.11	0.62	51.68	32.35	15.24	100.00

Table A7. Measures of women's intra-household decision-making power, DHS, 2015–16.

Household decisions	% joint decisions by women & men	% of independent decisions by women
How to spend women's earnings	50.26	26.94
Access to women's health care	50.13	18.70
Large household purchases	49.24	8.34
Visits to family or relatives	61.82	17.01

A.2. Conceptual framework (extended)

This section presents an analytical application of the theoretical model and derives comparative statics. We assume the individuals' utilities are of quasilinear functional form and the production set for firewood collection is convex. Next, we derive comparative statics for the effects of energy prices and female bargaining power on the household's optimal demand for firewood.

A.2.1. Firewood collection and cost minimisation

We first derive the conditional labour demand for firewood collection for a generic convex production technology, subsequently allowing for decreasing returns to scale in production. Consider the following two input production functions, with parameters $\beta, \gamma > 0$:

$$F = L_{\text{wf}}^{\beta} L_{\text{wm}}^{\gamma} \tag{6}$$

where L_{wf} and L_{wm} denote women's and men's respective labour inputs for firewood collection. The household's cost minimisation problem yields the following first-order condition:

$$\frac{\beta}{\gamma}\frac{L_{wm}}{L_{wf}} = \frac{w_f}{w_m}. \tag{7}$$

The conditional labour demand functions are obtained as follows:

$$L^c_{wf} = F^{\frac{1}{\beta+\gamma}} A_f \tag{8}$$

where $A_f = \left(\frac{\beta}{\gamma}\frac{w_m}{w_f}\right)^{\frac{\gamma}{\beta+\gamma}}$, $A_f > 0$.

$$L^c_{wm} = F^{\frac{1}{\beta+\gamma}} A_m \tag{9}$$

where $A_m = \left(\frac{\beta}{\gamma}\frac{w_m}{w_f}\right)^{\frac{-\beta}{\beta+\gamma}}$, $A_m > 0$.

A.2.2. Utility maximisation

We assume the utility function is quasilinear, strictly concave and twice-differentiable. An individual's utility is linear in purchased energy sources M and follows a Cobb–Douglas form for firewood F and private leisure l_i for person i. The quasilinear functional form implies that firewood and leisure will not exhibit wealth effects, with all additional income spent on the market energy good, M. This may be reasonable if firewood is considered a subsistence good for basic energy needs, with households relying on market energy sources for additional energy requirements. The individual's utility maximisation problem is modelled as follows:

$$\max_{l_i, L_{wi}} \quad U_i = M + F^{\alpha_i} l_i^{1-\alpha_i} \quad \alpha_i \in (0,1) \tag{10}$$

such that

$$w_i l_i \leqslant w_i (T - L_{wi}) + \rho_i \tag{11}$$

$$0 \leqslant l_i \leqslant T - L_i - L_{wi} \tag{12}$$

where L_i is the individual's market labour supply. Here, ρ_i is individual i's private resource share, which itself is determined from the intra-household bargaining process. The individual's objective is to optimise their time allocation between market work and leisure, conditional on firewood production, F. The optimal time spent on firewood collection by each individual is obtained from the first-order condition of the production function and equals the conditional labour demand functions (equations (8) and (9)). The budget constraint is modified as follows:

$$w_i l_i \leqslant w_i \left(T - F^{\frac{1}{\beta+\gamma}} A_i\right) + \rho_i. \tag{13}$$

The first-order conditions (FOCs) for the second-stage problem are as follows:

$$\frac{\partial L}{\partial l_i} = (1-\alpha_i) F^{\alpha_i} l_i^{-\alpha_i} + \lambda w_i = 0 \tag{14}$$

$$\frac{\partial L}{\partial F} = \alpha_i F^{\alpha_i - 1} l_i^{1-\alpha_i} + \lambda \frac{w_i A_i}{\beta+\gamma} F^{\frac{1}{\beta+\gamma}-1} = 0. \tag{15}$$

The conditional leisure demand function for person i is thus

$$l_i^* = F^{\frac{1}{\beta+\gamma}} B_i \tag{16}$$

where $B_i = \frac{1-\alpha_i}{\alpha_i}\frac{A_i}{\beta+\gamma}$, $B_i > 0$. We assume $F > 0$ and hence $l_i > 0 \quad \forall i$. Thus, we will only explore interior solutions for $\{F, l_i\}$.

Next, the household's utility maximisation problem is as follows:

$$\max_{M,F,\rho_m,\rho_f} \quad \phi\, U_f\left(M, F, l_f^*\right) + (1-\phi)\, U_m\left(M, F, l_m^*\right) \tag{17}$$

s.t.

$$\rho_m + \rho_f = y - P_m M - w_f L_{wf} - w_m L_{wm} \tag{18}$$

where ϕ and $(1-\phi)$ denote the bargaining weight for women and men, respectively. We substitute for the conditional leisure demand functions (equation (16)) and the conditional labour demand functions (equations (8) and (9)) in the household's utility maximisation problem:

$$\max_{M,F,\rho_m,\rho_f} \quad V = M + \phi F^{\alpha_f}\left(F^{\frac{1}{\beta+\gamma}}B_f\right)^{1-\alpha_f} + (1-\phi)F^{\alpha_m}\left(F^{\frac{1}{\beta+\gamma}}B_m\right)^{1-\alpha_m} \tag{19}$$

s.t.

$$\rho_m + \rho_f = y - P_m M - w_f F^{\frac{1}{\beta+\gamma}} A_f - w_m F^{\frac{1}{\beta+\gamma}} A_m. \tag{20}$$

We now relax the assumption of constant returns to scale in production, and specifically model the case of decreasing returns to scale, i.e. $\beta+\gamma<1$. By relaxing the assumption of constant returns to scale, we allow for firewood to be a common pool resource in the natural environment and potentially be depleted due to unsustainable collections from forests. Decreasing returns to scale in production thus allow for increasing rather than constant marginal costs. This may better reflect ground realities where individuals often walk increasingly longer distances to gather wood and spend longer hours segregating high-quality biomass from lower-grade wood, twigs and leaves (Jagger and Shively 2014, Bošković *et al* 2023).

The FOCs for the first-stage problem with respect to energy consumption are as follows:

$$\frac{\partial L}{\partial M} = 1 + \lambda P_m = 0 \tag{21}$$

$$\Rightarrow \lambda = \tfrac{-1}{P_m}.$$

$$\frac{\partial L}{\partial F} = \phi B_f^{1-\alpha_f}\left(\alpha_f + \frac{1-\alpha_f}{\beta+\gamma}\right)F^{(1-\alpha_f)\left(\frac{1}{\beta+\gamma}-1\right)} + (1-\phi)B_m^{1-\alpha_m}\left(\alpha_m + \frac{1-\alpha_m}{\beta+\gamma}\right)F^{(1-\alpha_m)\left(\frac{1}{\beta+\gamma}-1\right)} + \lambda F^{\frac{1}{\beta+\gamma}-1}\left(\frac{w_f A_f + w_m A_m}{\beta+\gamma}\right) = 0.$$

Substituting for the value of λ, the Walrasian demand equation for firewood, in implicit form, simplifies to

$$\phi C_1 F^{\alpha_f\left(1-\frac{1}{\beta+\gamma}\right)} + (1-\phi)C_2 F^{\alpha_m\left(1-\frac{1}{\beta+\gamma}\right)} = \frac{C_3}{P_m} \tag{22}$$

where $C_1 = B_f^{1-\alpha_f}(\alpha_f + \frac{1-\alpha_f}{\beta+\gamma})$, $C_2 = B_m^{1-\alpha_m}(\alpha_m + \frac{1-\alpha_m}{\beta+\gamma})$ and $C_3 = \left(\frac{w_f A_f + w_m A_m}{\beta+\gamma}\right)$, and $C_1, C_2, C_3 > 0$. The demand for firewood in implicit form thus depends on a number of exogenous parameters, including an individual's preferences, the Cobb–Douglas share parameters in firewood production, adult wage rates and the price of market energy sources. However, it does not depend on endogenous private resources. It is further independent of the household's non-labour income, y, due to the assumption of quasilinear preferences, wherein all additional income is allocated to consumption of market energy sources, M.

A.2.3. Comparative statics

We now derive comparative statics to analyse the change in firewood demand due to an increase in the price of marketed energy items, P_M, and increases in female bargaining power, ϕ. In this model, we cannot, however, investigate the effects of exogenous increases in income (such as through cash transfers) due to the assumption of quasilinear preferences and the absence of wealth effects[7].

$$\frac{\partial F}{\partial P_m} = \frac{C_3}{P_m^2\left[\alpha_f\left(\frac{1}{\beta+\gamma}-1\right)\phi C_1 F^{\alpha_f\left(1-\frac{1}{\beta+\gamma}\right)-1} + \alpha_m\left(\frac{1}{\beta+\gamma}-1\right)(1-\phi)C_2 F^{\alpha_m\left(1-\frac{1}{\beta+\gamma}\right)-1}\right]}. \tag{23}$$

As there are no income effects in this model, the net effect of increases in market energy prices on firewood demand is fully captured by the substitution effect, which is positive between the two fuels, i.e. $\frac{\partial F}{\partial P_m} > 0$, since the denominator of the right-hand side (rhs) is positive (due to decreasing returns), and the C_i terms are also positive.

However, the effect of an increase in female bargaining power on firewood demand, $\frac{\partial F}{\partial \phi}$, is more complex:

$$\frac{\partial F}{\partial \phi} = \frac{C_2 F^{\alpha_m\left(1-\frac{1}{\beta+\gamma}\right)} - C_1 F^{\alpha_f\left(1-\frac{1}{\beta+\gamma}\right)}}{\phi C_1 \alpha_f\left(1-\frac{1}{\beta+\gamma}\right)F^{\alpha_f\left(1-\frac{1}{\beta+\gamma}\right)-1} + (1-\phi)C_2\alpha_m\left(1-\frac{1}{\beta+\gamma}\right)F^{\alpha_m\left(1-\frac{1}{\beta+\gamma}\right)-1}}. \tag{24}$$

[7] This model is stylised for exposition and can be expanded to account for wealth effects (Aggarwal 2025).

Due to decreasing returns to scale in firewood production, the denominator of the rhs is negative. The overall change in firewood demand due to an increase in female bargaining power will be negative if and only if $\frac{C_2}{F^{\alpha_m(\frac{1}{\beta+\gamma}-1)}} > \frac{C_1}{F^{\alpha_f(\frac{1}{\beta+\gamma}-1)}}$. The model therefore does not lead to unambiguous predictions about the direction of change in firewood consumption due to increases in women's bargaining power within the household. This effect depends in a complex manner on both adults' preferences for firewood consumption vis-à-vis leisure, their market wage rates, their productivity of firewood collection and the overall returns to scale of the production technology.

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