Article

Fuel Skipping or Fuel Switching? Stage-Specific Barriers to Household Cooking-Fuel Transitions in Bangladesh

Md Ubaydullah*

Abstract

In the Bangladesh cooking-fuel context, the energy-ladder hypothesis implies a possible sequence from dung or agricultural waste to wood and then to gas, with wood serving as the transitional fuel. This paper tests that implication using household-level data from the Bangladesh Quarterly Labour Force Survey 2016–17. The analysis combines a multinomial logit model with wood as the reference outcome, complementary sequential binary logit estimates, and rural-urban subsample analyses to examine whether the observed fuel-choice structure is consistent with stepwise fuel switching or with fuel skipping. The results do not support a stepwise dung-wood-gas sequence. Wealth, education, urban residence, and female headship are associated with reduced dung use and higher gas use, but not with a corresponding rise in wood use as the primary fuel. The sequential estimates further indicate that the dung-exit margin and the gas-adoption margin show different coefficient structures, with affordability and supply-side correlates particularly relevant at the gas margin. The pattern is most visible in urban areas, while wood persists more in rural settings.

1. Introduction

Household cooking-fuel transition remains a major development and environmental challenge in low- and middle-income countries. Despite progress in electrification and broader energy access, more than two billion people still rely on polluting fuels such as wood, crop residue, dung, charcoal, coal, and kerosene for cooking, with important consequences for health, time use, and the environment (IEA et al., 2025; WHO, 2025). Bangladesh is a par-

*Third-year PhD student, Graduate School of Economics, Ritsumeikan University 1-1-1 Noji-Higashi, Kusatsu, Shiga 525-8577 Japan
E-mail: gr0659pk@ed.ritsumei.ac.jp

ticularly relevant case because clean-cooking access has improved only gradually, while biomass remains widely used, especially in rural areas and among less advantaged households (Aziz et al., 2022). In the Bangladesh Quarterly Labour Force Survey (QLFS) 2016–17 sample used here, wood accounts for 43.2% of the three-fuel sample, followed by dung at 32.4% and gas at 24.4%, making wood's transitional role especially important to examine. The Bangladesh case therefore provides a useful setting for assessing whether fuel transition follows a sequential pathway or a more discontinuous pattern.

The standard energy-ladder framework predicts that as income, education, infrastructure, and other socioeconomic conditions improve, households move progressively from traditional biomass fuels to cleaner and more efficient modern fuels (Hosier & Dowd, 1987; Leach, 1992; Van Der Kroon et al., 2013). In the cooking-fuel context, this implies a sequence from dung or agricultural waste to wood or firewood and then to gas or LPG. Yet this ordering is rarely tested directly at the level of specific fuels. A central implication of the ladder is that wood should function as an intermediate rung: if households upgrade in a stepwise manner, improvements in socioeconomic status should be associated with greater use of wood at some stage before the move to gas. If, however, households reduce dung use and increase gas use without a corresponding rise in wood use, the observed pattern would be more consistent with fuel skipping than with a strict sequential transition (Dominguez et al., 2021; Murphy, 2001).

Existing studies on household cooking-fuel choice in Bangladesh provide important evidence on the socioeconomic correlates of cleaner fuel adoption. Research has shown that income, education, urban residence, gender-related household characteristics, and access conditions are associated with cleaner cooking-fuel use (Aziz et al., 2022; Haq et al., 2024; Hasan & Mozumder, 2017; Mottaleb et al., 2017). This literature identifies who is more likely to adopt cleaner fuels, but it does not directly test whether wood occupies the intermediate position between dung and gas implied by the energy-ladder framework.

This paper addresses that gap by asking whether the observed household cooking-fuel choice structure in Bangladesh is more consistent with sequential fuel switching or with fuel skipping. Specifically, it examines whether the main socioeconomic correlates of fuel upgrading (wealth, education, urban residence, and female headship) raise wood use as part of a stepwise transition, or whether they reduce dung use and raise gas use without a similar pattern for wood. This distinction matters because a positive association with gas alone does not confirm the energy-ladder sequence. A stepwise dung-wood-gas pathway would also require socioeconomic advancement to be associated with greater wood use at the middle category.

The analysis uses household-level data from the QLFS 2016–17 and focuses on three dominant primary cooking fuels: dung or agricultural waste, wood or firewood, and gas or LPG. The baseline specification is a multinomial logit model with wood as the reference

outcome, allowing dung and gas to be compared directly against the candidate transitional fuel. A complementary sequential binary logit model separates the non-dung margin from the gas-versus-wood margin, while rural-urban subsample analyses examine whether the structure of transition differs across locations.

The cross-sectional fuel-choice structure does not support the pattern expected under a stepwise dung-wood-gas-sequence. Wealth, education, urban residence, and female headship are associated with reduced dung use and higher gas adoption, while their associations with wood use are weak, negative, or statistically insignificant. This pattern is more consistent with fuel skipping than with a sequence in which households accumulate at the wood stage before adopting gas. The sequential analysis further indicates that the dung-exit margin and the gas-adoption margin show different coefficient structures: wealth, education, and urban residence carry larger associations at the gas margin. The rural-urban subsample analyses suggest that this pattern is most visible in urban areas, while wood use remains more persistent in rural households.

The paper makes two contributions. First, it treats wood not as an assumed intermediate rung but as an empirical test case, so the question becomes whether the observed structure of primary fuel choice is consistent with a sequential pathway, rather than only who adopts cleaner fuels. Second, it moves the Bangladesh clean-cooking literature beyond binary clean-versus-polluting classifications to the structure of primary fuel choice across dung, wood, and gas as separate outcomes.

The remainder of the paper is organised as follows. Section 2 reviews the relevant literature. Section 3 describes the data and empirical strategy. Section 4 presents the results and discussion, and section 5 concludes.

2. Literature review

2.1 Energy-ladder theory and critiques

The energy-ladder hypothesis explains household fuel transition as a gradual movement from traditional biomass to cleaner and more efficient modern fuels as income, education, and access improve. In this framework, fuels are ordered hierarchically, with dung, crop residues, and firewood at the lower end, intermediate fuels in the middle, and LPG, natural gas, or electricity at the upper end (Hosier & Dowd, 1987; Leach, 1992). For Bangladesh, this implies a possible sequence from dung or agricultural waste to wood or firewood and then to gas or LPG, with wood occupying the middle position.

The strict linear version of this framework has been widely challenged. Households often accumulate fuels rather than replace one fuel with another, producing multiple-fuel use or fuel stacking (Masera et al., 2000). This critique weakens the assumption that households

must pass through each rung in a fixed sequence. Van Der Kroon et al. (2013), synthesising the empirical literature, similarly show that income-driven fuel switching is often incomplete and that biomass frequently persists even when cleaner fuels are adopted. Their findings suggest that fuel transition depends not only on household income but also on markets, infrastructure, and fuel availability. These critiques open the possibility of a third pattern: fuel skipping, where households appear to bypass the intermediate fuel category rather than accumulate at it (Dominguez et al., 2021; Murphy, 2001).

2.2 Non-linear transition, access constraints, and fuel skipping

A major reason why household fuel transition may be non-linear is that modern-fuel adoption depends not only on income but also on access, affordability, and infrastructure. Heltberg (2004) shows that spontaneous movement along a clean-fuel hierarchy is limited and that biomass often remains dominant where modern-fuel markets, electrification, or supply networks are weak. This implies that households with similar socioeconomic characteristics may choose different fuels depending on whether LPG, piped gas, refill markets, and transport systems are locally available. Fuel transition is therefore shaped by the interaction between household capacity and the external fuel-market environment, rather than by income alone.

The critique of the linear ladder also opens space for the idea of fuel skipping. Fuel skipping is related to, but distinct from, fuel stacking. Fuel stacking refers to the simultaneous use of multiple fuels (Masera et al., 2000; Shankar et al., 2020), whereas fuel skipping or leapfrogging refers to an observed pattern in which households do not appear to accumulate at the intermediate fuel category but are instead more likely to be observed with lower traditional-fuel use and higher modern-fuel use (Dominguez et al., 2021; Murphy, 2001). In this study, fuel skipping refers to a primary-fuel pattern in which the main socioeconomic correlates of fuel upgrading are associated with reduced dung use and higher gas use, but not with higher wood use. This does not imply that individual households are directly observed moving from dung to gas. Rather, it indicates that the cross-sectional fuel-choice structure is more consistent with bypassing wood than with a stepwise transition through wood.

Wood is therefore the key test case for Bangladesh. If a sequential energy-ladder interpretation fits the data, wood should operate as the middle category between dung or agricultural waste and gas or LPG, and socioeconomic advancement should be associated with greater wood use at some stage of the transition. By contrast, if wealth, education, urban residence, and female headship reduce dung use and increase gas use without increasing wood use, the observed pattern would not support a stepwise ladder through wood. It would instead suggest a more non-linear transition in which wood does not function as the expected transitional fuel. It is worth noting that a strict cross-sectional implication of the

dung-wood-gas ladder is that households at intermediate socioeconomic positions should be more likely to use wood as their primary fuel. If wood use does not rise with socioeconomic advancement, this weakens the interpretation of wood as the current intermediate rung in the observed fuel-choice structure, even if wood played a transitional role historically.

2.3 Evidence from Bangladesh

Bangladesh provides a relevant setting for examining whether household cooking-fuel transition follows a sequential ladder or a more non-linear pattern. Biomass remains central to household cooking: the Climate Policy Initiative reports that about 75% of cooking fuel use in Bangladesh comes from biomass sources, including straw/leaf, husk/bran, and jute stick/wood/bamboo (Sustainable Energy for All & Climate Policy Initiative, 2020). Annual household biomass consumption stood at 44 million tonnes, representing 79% of the country's total biomass consumption (GOB, 2013). At the same time, clean cooking remains highly uneven across space. Haq et al. (2024) show that clean-energy adoption was 59.5% among urban households but only 8.7% among rural households, a gap of 50.8 percentage points. LPG has expanded rapidly as piped-gas connections remain limited, but this expansion has not eliminated rural biomass dependence.

Income and wealth are the most consistent predictors in Bangladesh's clean-cooking literature, consistent with the broader pattern identified in Lewis and Pattanayak's (2012) systematic review across developing-country studies. Mottaleb et al. (2017) show that income, education, urban residence, and female headship are positively associated with clean-energy use and expenditure. Cleaner energy demand rises more clearly after households reach higher expenditure levels, indicating a non-linear income relationship (Hasan & Mozumder, 2017). Both studies focus on clean-versus-dirty fuel categories or expenditure shares and do not model dung, wood, and gas as distinct primary-fuel outcomes.

Recent studies strengthen this evidence base but retain similar modelling choices. Using ordered probit and ordered logit models, Aziz et al. (2022) show that household wealth is associated with cleaner cooking technology and fuel choice, but the ordered framework assumes a fixed fuel ranking rather than testing whether wood behaves as a distinct intermediate category. Haq et al. (2024) use an extended probit model and Blinder-Oaxaca decomposition to examine the rural-urban disparity in clean-energy adoption, but the binary clean-versus-polluting outcome cannot distinguish dung from wood.

A smaller set of mechanism-oriented studies deepens the understanding of biomass persistence and LPG uptake. Barua et al. (2025) show that livestock, land, and agricultural by-products sustain dung and other biomass use, while Dey et al. (2024) document continued heavy biomass reliance in rural and coastal settings because of local availability and practical cooking constraints. Hassan (2020) shows that liquidity shocks such as remittance inflows can facilitate LPG adoption, suggesting that modern-fuel uptake depends not only on

permanent income but also on short-run cash availability. These studies identify the socio-economic and contextual correlates of cleaner cooking, but none directly examines whether wood occupies the intermediate position between dung and gas, which is the specific question this paper addresses.

2.4 Research gap and contribution

The Bangladesh literature has established the main socioeconomic and contextual correlates of cleaner cooking, but it has not directly examined whether the observed fuel-choice structure is consistent with a dung-wood-gas sequence or with a non-linear pattern. The methodological tools used so far make this difficult to assess. Existing Bangladesh studies mainly use binary clean-versus-polluting outcomes or ordered models that impose a fixed fuel hierarchy from traditional to modern fuels. These specifications cannot show whether the same household characteristics that are associated with leaving dung also raise wood use at some point, or whether the gas association arises without a corresponding rise in wood use. To address this gap, the present study uses a multinomial logit model with wood as the reference outcome and a complementary sequential binary logit that separates the non-dung margin from the gas-versus-wood margin. This structure allows the data to reveal whether the correlates of fuel upgrading operate differently at the two margins. The rural-urban subsample analyses then test whether the patterns identified in the full sample hold within each setting, given that gas access, LPG distribution, and biomass availability differ sharply between rural and urban areas in Bangladesh.

3. Data and empirical strategy

3.1 Data and sample

This study uses the Bangladesh Quarterly Labour Force Survey (QLFS) 2016-17, conducted by the Bangladesh Bureau of Statistics (BBS). The QLFS is a nationally representative household survey that collects information on various socio-economic characteristics. The unit of analysis is the household, and household-head characteristics are used as explanatory variables. The analysis is restricted to households that report one of the three dominant primary cooking fuels: dung or agricultural waste, wood or firewood, and gas or LPG. Less common fuel categories, including biogas, kerosene, electricity, and other fuels are excluded, because these categories are small and not central to the paper's dung-wood-gas comparison. This restriction allows the analysis to focus on the principal margins of household cooking-fuel choice in Bangladesh. Table 1 reports the summary statistics for the variables used in the analysis.

Table 1: Summary Statistics

	Observations	Mean	SD	Min	Max
Wood	121,285	0.431	0.495	0	1
Dung	121,285	0.325	0.468	0	1
Gas	121,285	0.244	0.430	0	1
Rural	121,285	0.508	0.500	0	1
Urban	121,285	0.492	0.500	0	1
Household size	121,285	4.035	1.666	1	25
No. of women in HH	121,285	1.837	0.974	0	13
Female headed	121,285	0.139	0.346	0	1
Age	121,285	45.389	13.803	14	99
Muslim	121,285	0.899	0.301	0	1
Wealth index	121,285	0.085	1.352	−1.702	3.013
Primary (1-5)	121,285	0.242	0.428	0	1
Secondary (6-10)	121,285	0.283	0.450	0	1
Higher secondary (11+)	121,285	0.128	0.334	0	1

3.2 Empirical strategy

To examine whether household cooking-fuel choices in Bangladesh are consistent with a sequential energy-ladder transition through wood or with fuel skipping from dung toward gas, this study uses a multinomial logit model with three mutually exclusive outcomes: dung, wood, and gas. Wood is used as the reference outcome because the paper asks whether wood occupies the intermediate position between dung and gas. In a multinomial logit model, the reference category affects the interpretation of log-odds coefficients but does not change predicted probabilities or average marginal effects (Long and Freese, 2014; Train, 2009). With wood as the reference, the model compares dung relative to wood and gas relative to wood. However, the main results are presented as average marginal effects on predicted probabilities. If household characteristics are associated with lower dung use and higher gas use without a corresponding increase in wood use, the pattern is more consistent with fuel skipping than with a smooth transition through wood.

Let Fuel_i denote the primary cooking fuel used by household i, where the possible outcomes are dung, wood, and gas. The multinomial logit probability that household i chooses fuel j is:

$$\Pr(\mathrm{Fuel}_i = j \mid X_i) = \frac{\exp(\alpha_j + X_i'\beta_j)}{\sum_k \exp(\alpha_k + X_i'\beta_k)} \tag{1}$$

Because wood is the reference outcome, the wood equation is normalised to zero. The two estimated equations are:

$$\log\left[\frac{\Pr(\mathrm{Fuel}_i = \mathrm{dung})}{\Pr(\mathrm{Fuel}_i = \mathrm{wood})}\right] = \alpha^D + \rho_1^D \mathrm{FH}_i + \rho_2^D \mathrm{U}_i + \rho_3^D (\mathrm{FH}_i \times \mathrm{U}_i) + \mathrm{H}_i'\tau^D + \delta^D \tag{2}$$

$$\log\left[\frac{\Pr(\text{Fuel}_i=\text{gas})}{\Pr(\text{Fuel}_i=\text{wood})}\right]=\alpha^G+\rho_1^G FH_i+\rho_2^G U_i+\rho_3^G(FH_i\times U_i)+H_i'\tau^G+\delta^G \quad (3)$$

where FH_i is an indicator equal to one if the household head is female, U_i is an indicator equal to one for urban households, and $FH_i \times U_i$ allows the female-headship association to differ between rural and urban settings. Female headship is included as a proxy for gender dynamics in fuel choice, since cooking-fuel decisions are linked to women's domestic responsibilities, exposure to biomass smoke, and household resource allocation (Choudhuri & Desai, 2020; Odo et al., 2021). Urban residence captures rural-urban differences in fuel-market development and access to modern fuels, which are central to examining whether households move through wood or bypass it toward gas (Heltberg, 2004; Lewis & Pattanayak, 2012). The interaction term is included because the relationship between female headship and fuel choice may depend on the local fuel-market context. The vector H_i includes several socio-economic factors that may influence fuel choice. Wealth and education capture the economic and human-capital dimensions of the energy-ladder framework. Wealth reflects the household's capacity to meet the upfront cost of modern cooking appliances and the recurring cost of gas or LPG, both of which may constrain clean-fuel adoption (Mottaleb et al., 2017). The wealth index is constructed using principal component analysis applied to six binary housing and asset indicators: domestic worker presence, land ownership, housing ownership, housing structure quality, access to safe drinking water, and access to improved sanitation. Fuel-related assets and cooking equipment are excluded from the index construction to avoid the correlation between the wealth measure and the fuel-choice outcome. The six indicators reflect housing quality and basic service access, following the DHS wealth index methodology (Rutstein, 2015). The first principal component is retained and rescaled so that higher values indicate greater wealth. Education may influence awareness of fuel quality, health risks, and the ability to adopt and sustain modern fuels (Lewis & Pattanayak, 2012). The remaining covariates—household size, number of women in the household, age of the household head, and Muslim identity—serve as controls. Household size captures household scale and potential cooking-energy demand, while the number of women in the household captures gender composition conditional on household size (Aziz et al., 2022; Dey et al., 2024). Age of the household head accounts for life-cycle and generational differences in fuel-use practices (Haq et al., 2024). Muslim identity is used as a proxy for cultural norms related to food preparation and household practices that may be correlated with cooking-fuel choice in Bangladesh. District fixed effects absorb time-invariant local characteristics, including fuel-market conditions, gas pipeline coverage, and regional infrastructure. Standard errors are clustered at the primary sampling unit level.

Because multinomial logit coefficients are expressed in log-odds units, the main results are presented using average marginal effects (AMEs). For covariate x and outcome j, the

AME is:

$$AME_j^x = \frac{1}{N}\sum_i \frac{\partial Pr(Fuel_i = j \mid X_i)}{\partial x_i} \tag{4}$$

AMEs are interpreted as average changes in predicted probabilities. For continuous variables, they represent the average probability change associated with a one-unit increase in the covariate; for binary variables, they represent the average difference when the indicator changes from 0 to 1. Interaction terms are interpreted using predicted probabilities or conditional marginal effects rather than raw coefficients.

The multinomial logit model relies on the independence of irrelevant alternatives assumption, which requires the relative odds of choosing one fuel over another to be unaffected by the presence of the third alternative (Hausman & McFadden, 1984). Restricting the analysis to the three dominant cooking fuels makes the multinomial framework a reasonable starting point, although the IIA assumption remains a limitation of the approach. An ordered logit model is estimated as a specification check, the Brant test is used to assess the proportional-odds assumption, and AIC and BIC are compared across specifications (Brant, 1990).

As a complementary analysis, the paper also estimates sequential binary logit models, which decompose fuel choice into two conditional margins (Kar et al., 2024; Nagakura & Kobayashi, 2009). Stage 1 examines whether the household uses a non-dung fuel, while Stage 2 examines whether non-dung households use gas rather than wood. This structure provides additional evidence on whether the dung-exit and gas-adoption margins are associated with different household characteristics.

Stage 1:

$$Pr(Stage1_i = 1 \mid X_i) = \Lambda(\alpha^1 + \beta_1^1 FH_i + \beta_2^1 U_i + \beta_3^1 (FH_i \times U_i) + H_i' \gamma^1 + \delta_d^1) \tag{5}$$

where $Stage1_i = 1$ if the household uses wood or gas, and $Stage1_i = 0$ if it uses dung.

Stage 2:

$$Pr(Stage2_i = 1 \mid X_i,\ Fuel_i \neq dung) = \Lambda(\alpha^2 + \beta_1^2 FH_i + \beta_2^2 U_i + \beta_3^2 (FH_i \times U_i) + H_i' \gamma^2 + \delta_d^2) \tag{6}$$

where $Stage2_i = 1$ if the household uses gas, and $Stage2_i = 0$ if it uses wood. The sequential structure helps assess whether the household characteristics associated with non-dung use differ from those associated with gas adoption among non-dung households.

To assess whether selected covariates operate differently across the two stages, the Stage 1 and Stage 2 equations are compared using seemingly unrelated estimation with PSU-clustered standard errors. For each covariate *m*, the null hypothesis is:

$H_0 : \beta_m^1 = \beta_m^2$

Rejection of the null indicates that the coefficient differs statistically across stages. These tests are conducted on logit coefficients rather than AMEs and should therefore be interpreted as tests of cross-equation coefficient equality, not as direct tests of probability differences or causal transition effects.

4. Results and discussion

The results are organised in three subsections. Section 4.1 presents the baseline multinomial logit estimates. Section 4.2 presents the complementary sequential binary logit results and assesses what they add to the baseline picture. Section 4.3 examines the rural and urban subsample estimates.

4.1 Baseline results: multinomial logit

Wealth, education, urban residence, and female headship are each associated with a lower predicted probability of dung use and a higher predicted probability of gas use, while their associations with wood are negligible or negative (Table 2). This pattern is inconsistent with the energy-ladder prediction that wood use should rise at an intermediate stage before gas adoption and is more consistent with fuel skipping from dung toward gas.

The wealth index is associated with a 2.1 percentage-point lower predicted probability of dung use and a 1.1 percentage-point lower predicted probability of wood use, while the predicted probability of gas use rises by 3.2 percentage points. Both biomass categories are lower at higher wealth levels, and the average marginal effect provides no evidence of accumulation at wood as wealth rises. This is consistent with wealth being associated with lower financial barriers to gas adoption (both the upfront cost of LPG equipment and the recurring expenditure on refills), with higher-wealth households showing higher gas use rather than passing through a wood-intensive stage (Ansah et al., 2025).

Across all schooling levels, education is associated with lower dung use and higher gas use (Table 2). At primary and secondary levels, the predicted probability of wood use changes by less than one percentage point and is statistically insignificant in both cases, so that lower schooling levels are associated with reduced dung use without a corresponding change in wood use. At the highest level the picture changes sharply: higher secondary education is associated with a 7.1 percentage-point reduction in the predicted probability of wood use alongside an 18.8 percentage-point fall in dung use and a 25.9 percentage-point rise in gas use. At the highest education level, households are less likely to use wood, not more, which is the opposite of what the energy-ladder framework would predict for a

Table 2: Average marginal effects from multinomial logit model

	P(Dung)	P(Wood)	P(Gas)
Wealth index	−0.021***	−0.011***	0.032***
	(0.003)	(0.004)	(0.003)
Primary (1-5)	−0.045***	0.007	0.038***
	(0.004)	(0.005)	(0.004)
Secondary (6-10)	−0.107***	0.003	0.104***
	(0.005)	(0.006)	(0.005)
Higher secondary (11+)	−0.188***	−0.071***	0.259***
	(0.008)	(0.010)	(0.009)
Urban	−0.180***	−0.025*	0.206***
	(0.013)	(0.015)	(0.011)
Female headed	−0.016***	0.002	0.014***
	(0.005)	(0.006)	(0.004)
Household size	−0.001	0.006***	−0.006***
	(0.001)	(0.001)	(0.001)
No. of women in HH	−0.003*	0.002	0.000
	(0.001)	(0.002)	(0.001)
Age	−0.001***	−0.0001	0.001***
	(0.0001)	(0.0001)	(0.0001)
Muslim	0.004	−0.007	0.003
	(0.013)	(0.015)	(0.010)
Observations	121,285	121,285	121,285

Note: AMEs from multinomial logit with wood (fuel=1) as base outcome. Columns show marginal effects on P(Dung), P(Wood), and P(Gas). District fixed effects and PSU-clustered standard errors are included in all models. ***p<0.01 **p<0.05 *p<0.10

transitional fuel. The monotonic gradient, with the gas association growing faster than the dung association across schooling levels, suggests that education is associated specifically with gas use, consistent with more educated household heads being more likely to recognise the health costs of biomass smoke and to sustain the recurring costs of gas (Lewis & Pattanayak, 2012).

Urban households are associated with an 18.0 percentage-point lower predicted probability of dung use and a 20.6 percentage-point higher predicted probability of gas use. Urban residence is associated with a 2.5 percentage-point lower predicted probability of wood use, and this association is only marginally significant. This weak and negative association with wood is important: if urban location were associated with stepwise fuel upgrading, a meaningful positive association with wood would be expected alongside the gas association. Instead, the urban association is concentrated mainly at the dung-gas margin, consistent with urban areas offering better gas distribution networks and lower transaction costs for LPG that are associated with higher gas use rather than passage through a wood-intensive step (Aziz et al., 2022; Haq et al., 2024).

Female headship is associated with a 1.6 percentage-point lower predicted probability of dung use and a 1.4 percentage-point higher predicted probability of gas use. The associated change in the predicted probability of wood use is 0.2 percentage points and statistically insignificant. The female-headship association mirrors the pattern for wealth, education,

and urban location: it is concentrated at the dung-gas margin with no associated increase in the predicted probability of wood use. Female headship may capture differences in domestic decision-making, exposure concerns, and preferences for cleaner cooking when resources allow (Choudhuri & Desai, 2020). Female headship may also reflect widowhood, male out-migration, or other household circumstances that affect both resource constraints and fuel choice, so the coefficient should be interpreted as an association rather than direct evidence of gendered bargaining power. The modest magnitude relative to wealth and education is consistent with female headship reflecting a preference dimension of fuel choice conditional on economic capacity, rather than the capacity itself.

Among the control variables, household size is the only one with a substantively interpretable association. Each additional household member is associated with a 0.6 percentage-point higher predicted probability of wood use and a 0.6 percentage-point lower predicted probability of gas use, while the predicted probability of dung use is unchanged. This is consistent with a recurring-cost interpretation: larger households consume more fuel per period, where fixed-quantity LPG refills may represent a relatively larger expenditure burden, while wood can be obtained in smaller amounts (Barua et al., 2025; Dey et al., 2024). The number of women in the household, age of the household head, and Muslim identity are included as demographic controls; they show small or statistically insignificant associations with any fuel outcome, indicating that these characteristics are not independently associated with primary fuel choice once wealth, education, location, and headship gender are held constant.

The Wald tests in Table A1 reject equality of coefficients between the dung and gas equations for the selected variables, including wealth, higher secondary education, female headship, urban location, and household size (joint $\chi^2=2430.62$, $p<0.001$), indicating that each variable is associated differently with the two margins relative to wood. The Brant test rejects the proportional-odds assumption for the ordered logit ($\chi^2=12773.78$, $p<0.001$) and both Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) favour the multinomial specification, supporting the modelling choice (Brant, 1990). Taken together, the multinomial estimates are consistent with fuel skipping: across all four main variables, the characteristics associated with lower dung use are also associated with higher gas use, while their associations with wood are negligible or negative. The sign reversal for wood at higher secondary education, where the predicted probability of wood use falls alongside the predicted probability of gas rising, is the result most directly at odds with the energy-ladder prediction for a transitional fuel.

4.2 Complementary analysis: sequential binary logit

The sequential binary logit decomposes fuel choice into two conditional margins: Stage 1 models whether the household's primary fuel is non-dung, and Stage 2 models whether,

Table 3: Sequential binary logit—stage-specific AMEs

	Stage 1: Non-dung	Stage 2: Gas
Wealth index	0.023***	0.040***
	(0.003)	(0.004)
Primary (1-5)	0.044***	0.050***
	(0.004)	(0.006)
Secondary (6-10)	0.105***	0.133***
	(0.005)	(0.007)
Higher secondary (11+)	0.199***	0.308***
	(0.008)	(0.011)
Urban	0.181***	0.246***
	(0.013)	(0.016)
Female headed	0.014***	0.017***
	(0.005)	(0.006)
Household size	0.001	−0.008***
	(0.001)	(0.002)
No. of women in HH	0.002	0.001
	(0.002)	(0.002)
Age	0.001***	0.001***
	(0.0001)	(0.0001)
Muslim	−0.005	0.006
	(0.013)	(0.014)
Observations	121,285	81,927

Note: Stage 1: outcome = not using dung (wood or gas), full sample. Stage 2: outcome = gas use, non-dung subsample. District fixed effects and PSU-clustered standard errors are included in all models. ***p<0.01 **p<0.05 *p<0.10

Table 4: Cross-stage equality tests using SUEST

Variable	Stage 1 Non-dung vs dung	Stage 2 Gas vs wood	Difference	χ^2	p-value
Wealth index	0.240	0.372	0.132	7.44	0.006
Higher secondary education	2.033	2.668	0.635	34.21	<0.001
Urban location	1.655	2.213	0.558	7.81	0.005
Female headship	0.126	0.344	0.218	2.61	0.106
Household size	0.007	−0.074	−0.081	16.87	<0.001
Joint test	—	—	—	71.97	<0.001

Notes: Stage 1 contrasts non-dung households (wood or gas) with dung-using households. Stage 2 contrasts gas-using households with wood-using households among the non-dung sub-sample. The table reports logit coefficients, not average marginal effects. These tests assess cross-stage coefficient equality and should not be interpreted as tests of AME differences or causal transition effects.

among non-dung households, the primary fuel is gas rather than wood. Because Stage 1 groups wood and gas into a single non-dung category, it identifies the dung-exit margin but cannot distinguish the two non-dung fuels within that category. The sequential model is used as a complement to the multinomial baseline to assess whether the four main variables operate with different magnitudes across the two margins (specifically, whether the gas-adoption margin is associated with a different coefficient structure from the dung-exit margin).

Wealth is associated with a 2.3 percentage-point higher predicted probability of non-dung

fuel use at Stage 1 and a 4.0 percentage-point higher predicted probability of gas use at Stage 2 (Table 3). The Stage 2 estimate is nearly twice the Stage 1 estimate, and the corresponding coefficient comparison in Table 4 rejects equality across stages ($\chi^2=7.44$, $p=0.006$). The direction at both stages is consistent with the baseline finding in Table 2. What the sequential model adds is that the association between wealth and gas use is stronger at the gas-adoption margin than at the dung-exit margin, consistent with the recurring cost of LPG refills being more binding at the second margin.

Education shows the largest amplification across stages among the four main variables. Higher secondary education is associated with a 19.9 percentage-point higher predicted probability of non-dung use at Stage 1 and a 30.8 percentage-point higher predicted probability of gas use at Stage 2. The corresponding coefficient comparison in Table 4 also shows the largest statistically significant cross-stage difference among the variables tested ($\chi^2=34.21$, $p<0.001$). Primary and secondary education show positive and significant associations at both stages, with Stage 2 estimates consistently exceeding Stage 1. The direction at both stages supports the baseline finding, and the sequential structure adds that the education gradient, while present at both margins, is substantially steeper at the gas-adoption margin. This is consistent with education being associated with lower informational and cognitive barriers to gas adoption in ways that go beyond a general preference for non-biomass fuels (Lewis & Pattanayak, 2012).

Urban residence is associated with an 18.1 percentage-point higher predicted probability of non-dung use at Stage 1 and a 24.6 percentage-point higher predicted probability of gas use at Stage 2 ($\chi^2=7.81$, $p=0.005$). Urban location is the strongest predictor at both stages, and its association with gas adoption is larger than its association with non-dung use more generally. The sequential estimates suggest that the supply-side conditions concentrated in cities (gas market access, refill infrastructure, distribution density) are especially associated with gas use rather than with non-dung use in general, where education and wealth play a comparably large role.

Female headship is associated with a 1.4 percentage-point higher predicted probability of non-dung use at Stage 1 and a 1.7 percentage-point higher predicted probability of gas use at Stage 2. Both estimates are statistically significant. Unlike wealth, education, and urban location, the female-headship association does not intensify significantly at the gas-adoption margin (the cross-stage test does not reject equality, $\chi^2=2.61$, $p=0.106$). This distinguishes female headship from the other three main variables: it is associated with a general orientation toward cleaner primary fuels across both margins rather than a constraint that is specifically more binding at the gas-adoption stage.

The joint cross-stage equality test rejects coefficient equality across the selected variables ($\chi^2=71.97$, $p<0.001$), confirming that the dung-exit and gas-adoption margins are associated with different coefficient structures. For three of the four main variables (wealth,

education, and urban location), the gas-adoption margin shows stronger associations with each factor than the dung-exit margin. The stronger Stage 2 associations suggest that the gas-versus-wood margin is not merely a general non-dung margin; affordability and supply-side access appear to matter more strongly at this stage.

4.3 Rural and urban subsample analysis

Tables 5 and 6 report the multinomial logit and sequential logit estimates separately for rural and urban households. The subsample analysis examines whether the fuel-skipping pattern documented in the full sample holds within each location or is an artefact of pooling, and whether the rural-urban split reveals additional heterogeneity in how the four main variables are associated with fuel choice. The urban dummy and the female-headship interaction are excluded because the sample is already split by location.

The wealth estimates broadly support the baseline. In both rural and urban settings, greater wealth is associated with a lower predicted probability of dung use and a higher predicted probability of gas use (Table 5). The wealth-wood association, however, differs across locations: it is small and statistically insignificant in rural areas (−0.002) but negative and significant in urban areas (−0.026). In the full-sample model, wealth is associated with a 1.1 percentage-point lower predicted probability of wood use; the subsample estimates indicate that this is concentrated among urban households. In rural areas, the

Table 5: Rural and urban subsample AMEs

	Rural			Urban		
	P(Dung)	P(Wood)	P(Gas)	P(Dung)	P(Wood)	P(Gas)
Wealth index	−0.017***	−0.002	0.019***	−0.019***	−0.026***	0.046***
	(0.006)	(0.006)	(0.003)	(0.003)	(0.005)	(0.005)
Primary (1-5)	−0.038***	0.028***	0.009***	−0.058***	−0.014	0.072***
	(0.005)	(0.006)	(0.003)	(0.006)	(0.009)	(0.008)
Secondary (6-10)	−0.102***	0.071***	0.032***	−0.110***	−0.071***	0.181***
	(0.007)	(0.007)	(0.004)	(0.006)	(0.010)	(0.009)
Higher secondary (11+)	−0.181***	0.097***	0.084***	−0.172***	−0.232***	0.404***
	(0.012)	(0.012)	(0.008)	(0.008)	(0.013)	(0.012)
Female headed	−0.019**	0.009	0.010***	−0.012***	−0.007	0.019**
	(0.008)	(0.008)	(0.004)	(0.004)	(0.008)	(0.008)
Household size	−0.003	0.006***	−0.003***	0.001	0.007***	−0.008***
	(0.002)	(0.002)	(0.001)	(0.001)	(0.002)	(0.002)
No. of women in HH	−0.001	−0.001	0.002	−0.004**	0.004	−0.000
	(0.002)	(0.002)	(0.001)	(0.002)	(0.003)	(0.003)
Age	−0.001***	0.001***	0.0001	−0.001***	−0.001***	0.002***
	(0.0001)	(0.0001)	(0.0001)	(0.0001)	(0.0002)	(0.0001)
Muslim	0.003	−0.008	0.005	0.003	−0.005	0.003
	(0.023)	(0.022)	(0.008)	(0.011)	(0.019)	(0.017)
Observations	61,590	61,590	61,590	59,695	59,695	59,695

Note: AMEs from multinomial logit models are estimated separately for rural and urban households. Wood is the reference outcome in both models. District fixed effects and PSU-clustered standard errors are included in all models. The urban dummy and the female headship × urban interaction are excluded because the sample is split by location. AMEs are reported for P(dung), P(wood), and P(gas). ***p<0.01 **p<0.05 *p<0.10

Table 6: Rural and urban subsamples—sequential logit

	Rural		Urban	
	Stage 1	Stage 2	Stage 1	Stage 2
Wealth index	0.022***	0.036***	0.020***	0.047***
	(0.006)	(0.006)	(0.003)	(0.006)
Primary	0.037***	0.016***	0.060***	0.075***
	(0.006)	(0.005)	(0.006)	(0.009)
Secondary	0.102***	0.052***	0.112***	0.185***
	(0.007)	(0.008)	(0.006)	(0.011)
Higher secondary	0.181***	0.120***	0.177***	0.392***
	(0.013)	(0.012)	(0.008)	(0.013)
Female headed	0.020**	0.019***	0.012***	0.017*
	(0.008)	(0.007)	(0.005)	(0.009)
Household size	0.003	−0.007***	−0.001	−0.008***
	(0.002)	(0.002)	(0.001)	(0.002)
No. of women in HH	0.0003	0.004*	0.004**	−0.001
	(0.002)	(0.002)	(0.002)	(0.003)
Age	0.001***	0.0002	0.001***	0.002***
	(0.0001)	(0.0002)	(0.0001)	(0.0002)
Muslim	−0.003	0.001	−0.003	0.008
	(0.022)	(0.014)	(0.011)	(0.019)
Observations	61,590	28,031	58,835	51,813

Note: Stage 1: non-dung vs dung. Stage 2: gas vs wood (non-dung sample). Urban interaction excluded in subsample models. District fixed effects and PSU-clustered standard errors are included in all models.
***p<0.01 **p<0.05 *p<0.10

wealth-wood association is not statistically distinguishable from zero, so that greater wealth is associated with higher gas use without a corresponding reduction in wood use. The sequential subsample estimates (Table 6) show a stronger Stage 2 wealth association in urban areas (0.047) than in rural areas (0.036), consistent with the baseline interpretation that the wealth-gas association is stronger at the gas-adoption margin where supply conditions are more favourable.

Education generates the sharpest rural-urban contrast within this subsample analysis. At Stage 1 of the sequential model (Table 6), higher secondary education is associated with virtually the same increase in the predicted probability of non-dung use in rural areas (18.1 percentage points) and urban areas (17.7 percentage points). The divergence emerges sharply at Stage 2: higher secondary education is associated with a 12.0 percentage-point higher predicted probability of gas adoption in rural areas but a 39.2 percentage-point higher probability in urban areas, a gap of more than 27 percentage points. The multinomial estimates in Table 5 clarify the nature of this divergence. In rural areas, higher secondary education is associated with a 9.7 percentage-point higher predicted probability of wood use and an 8.4 percentage-point higher predicted probability of gas use, so that educated rural households appear at higher rates in both wood and gas. In urban areas, the same education level is associated with a 23.2 percentage-point lower predicted probability of wood use and a 40.4 percentage-point higher predicted probability of gas use, and the wood association changes sign entirely. The sign reversal indicates that the urban sub-

sample is where the observed pattern is most clearly consistent with fuel skipping. In rural areas, the same educational gradient is associated with lower dung use and higher gas use, but it is also associated with higher wood use. This suggests that education shifts rural households away from dung without producing a clear wood-bypass pattern. This is consistent with supply-side access conditions shaping whether demand-side characteristics translate into a fuel-skipping pattern or a more modest upward shift in fuel choice.

Female headship is associated with a lower predicted probability of dung use and a higher predicted probability of gas use in both rural and urban settings, with no significant association with wood in either location (Table 5). The sequential estimates (Table 6) show positive Stage 1 and Stage 2 associations in both subsamples with broadly similar magnitudes. The subsample results support the baseline finding: the female-headship pattern holds within each location and is not driven by the geographical distribution of female-headed households. The pattern is consistent with a preference-related association that operates regardless of the local fuel-market environment.

Among the control variables, household size is negatively associated with the predicted probability of gas adoption at Stage 2 in both rural (−0.007) and urban (−0.008) subsamples with comparable magnitudes (Table 6), and the multinomial estimates show the same positive wood, negative gas pattern in both locations (Table 5). This pattern is present across both settings and is consistent with the recurring-cost interpretation from the baseline and sequential models. Other control variables are largely statistically insignificant across both subsamples and both specifications.

The subsample results refine the central argument rather than restating it. The fuel-skipping pattern identified in the full sample is not uniform across space. The clearest contrast comes from the education estimates: the predicted probability of wood use is higher at higher education levels in rural areas but lower in urban areas. This sign reversal points to the urban fuel market, not education alone, as the setting in which the wood-bypass pattern is most apparent. In rural areas, higher socioeconomic endowments are associated with lower dung use and higher gas use, but the gas association is smaller than in urban areas and wood remains an important primary fuel within the non-dung category. The combination of household-level characteristics and local supply conditions appears to shape whether higher socioeconomic endowments map onto fuel skipping or a more gradual upward shift in fuel choice.

5. Conclusion

This paper examined whether household cooking-fuel choice in Bangladesh is consistent with a sequential energy-ladder pattern from dung to wood and then to gas, or whether

the observed primary-fuel structure is more consistent with fuel skipping. The central question was whether wood occupies the intermediate position predicted by the energy-ladder framework.

The results do not support a stepwise dung-wood-gas sequence. Wealth, education, urban residence, and female headship are generally associated with lower dung use and higher gas use, while their associations with wood are weak, negative, or statistically insignificant. This pattern is difficult to reconcile with a ladder model in which wood operates as the main transitional fuel. Instead, the evidence suggests that households with more favourable socioeconomic characteristics are more likely to be observed at the gas end of the fuel distribution without a corresponding rise in wood use.

The sequential logit analysis reinforces this interpretation by showing that the household characteristics associated with non-dung use are not identical to those associated with gas use among non-dung households. In particular, the associations for wealth, education, and urban location are consistently stronger at the gas-adoption margin than at the dung-exit margin, suggesting that affordability and supply-side access may be more relevant at the gas-adoption stage. The cross-sectional patterns therefore differ across the two margins. The rural-urban subsample analysis provides additional qualification: the fuel-skipping pattern is more visible in urban areas, while rural households show greater persistence of wood use. The observed departure from the energy-ladder sequence appears to depend not only on household socioeconomic characteristics but also on the local fuel-market environment.

The paper contributes to the household energy-transition literature by treating the intermediate step in the energy ladder as an empirical question rather than an assumption. For Bangladesh, wood should not be automatically read as a transitional fuel between dung and gas. More broadly, the findings suggest that clean-cooking transitions may follow non-linear pathways in which households do not necessarily accumulate at the intermediate fuel category before adopting modern fuels.

The policy implication is that clean-cooking strategies should not assume a uniform transition path through wood. In urban areas, where gas infrastructure is more developed, reducing LPG connection and refill costs may accelerate direct movement toward cleaner fuels. In rural areas, where wood use remains more persistent, effective policy may need to address LPG distribution networks and liquidity constraints alongside biomass availability. Policies that promote gas or LPG are unlikely to be sufficient unless they address the stage-specific constraints implicated in the observed cross-sectional patterns, including affordability, supply reliability, and local fuel-market access. At the same time, the persistence of wood use, especially outside urban areas, suggests that clean-cooking policy must also consider the practical conditions under which households continue to rely on biomass.

The analysis has important limitations. Because the data are cross-sectional, the paper

cannot observe household-level transitions over time or establish that individual households move directly from dung to gas. The data also identify only the primary cooking fuel, not the full household fuel portfolio, and therefore cannot capture fuel stacking in detail. Future research using panel data or richer fuel-use modules could examine whether the pattern observed here also appears in actual transition histories and among households that use multiple fuels simultaneously.

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Appendix

Table A1: Wald tests of equality between Dung and Gas equations in multinomial logit

Variable	χ^2	p-value
Wealth index	186.28	<0.001
Higher secondary	1637.07	<0.001
Urban location	380.15	<0.001
Female headship	12.67	<0.001
Household size	10.54	0.001
Joint test	2430.62	<0.001

Note: The table reports Wald tests of coefficient equality between the dung and gas equations in the multinomial logit model, with wood as the reference outcome. The null hypothesis is that the selected coefficients are equal across the dung and gas equations. Standard errors are clustered at the PSU level.

Table A2: Robustness check using ordered Logit and comparative model fit statistics

Test/model	Statistic	p-value/value
Ordered logit Wald χ^2	4316.90	<0.001
Brant test of parallel regression assumption	12773.78	<0.001
AIC: multinomial logit	131153.0	
AIC: ordered logit	150782.3	
BIC: multinomial logit	132628.6	
BIC: ordered logit	151529.8	

Note: Ordered logit is estimated as a robustness check. The Brant test rejects the parallel regression assumption; AIC/BIC favor the multinomial logit model.