National and Subnational Drivers for Cooking Energy Consumption in Rural India

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Abstract

Background: The energy transition pattern in India highlights that cooking continues to be the weakest link in the energy transition process for rural households. The government is trying to subsidize LPG for rural families to increase usage of LPG in India for a clean cooking energy transition. The paper endeavors to fill the void by revisiting the nature and degree of the rural energy transition for cooking in India.

Methodology: Using a multinomial logit model, the potential drivers at the individual household and group level have been identified. The group effect analysis has been conducted purposely to understand if social and cultural norms or -level factors within a village society affect the cooking energy transition of households in rural India and if that prevails over the income effect. At the sub-national level, an estimate of energy inequality has been derived by applying social choice-based Atkinson Inequality measure to examine the connection between higher energy inequality in primary fuel used for cooking and higher income inequality. In addition, the Brock-Dechert-Scheinkman (BDS) test on firewood consumption has been conducted for poor energy households from 38 districts of Bihar, one of the highest energy-poor states, to statistically examine the perceived nonlinearity in the dynamics of energy transition/fuel choice in cooking for rural households.

Results: The analysis at the national level indicates the importance of local and cultural factors that leads to the nonlinearity in the probability of the switchover from firewood to other clean fuel options.

Conclusions:

Summary: The paper highlights if subsidies on modern fuel and/or other cooking alternatives alone drive the transition process and examines the validity of the energy ladder hypothesis in the case of rural cooking energy transition and the drivers of the energy transition at the national and sub-national level.

Potential Implications: The state-level analysis done for Bihar and across various districts corroborates

this finding and provides an important direction towards local context-specific policy-making in the long term.

Keywords: *firewood, cooking energy, energy poverty, social group, energy ladder, nonlinearity*

Introduction

An analysis of the economics of transition offers a rich domain of ideas related to development stages, long waves, technological path-dependency, conflict resolution, public investments, the emergence of institutions and, transitions from a socialist to a market-driven country. Even though mainstream economic disciplines do posit a conflict in studying other transition-related areas like energy transition, it is, however, clear that there are many areas from economic disciplines which can be applied for even energy transition research (Van den Bergh, J., & Kemp, R. (2006)).

Moreover, the economic development of a nation is interwoven with the increase in energy consumption and transition (Gurtu, Searcy, & Jaber, 2016). However, the process of transition from one form of energy to another is quite complex. There are a plethora of factors that underpin this complexity in the energy transition. For instance, the speed, timing, and temporal dynamics of a place are important in assessing, determining energy transition in rural areas (Sovacool, 2016). Furthermore, bringing clarity in the understanding of the energy transition process also requires integrating insights from the physical and social sciences with the process of technology evolution and adoption (Sovacool, 2015). The technological evolution or the adoption of a new technology lies at the heart of the energy transition process. This becomes more important at the family level and depends on the social construct of the families. The social construct, in turn, is influenced by the institutional and administrative arrangements, organizational forms, production and labor processes, relationship with nature, daily activities of life, and above all, behavioral and cultural issues (Harvey, 2011).

The paradigm of the energy transition in cooking in a rural context deals with day-to-day human interaction and is deeply intertwined with cultural and behavioral practices. A recent

study by Akintan et al. (2018) reinforces that "ethnicity," "taboos," "cultural practices" act as important drivers in the rural energy transition process from firewood to other improved cooking stoves for cooking in developing countries. Vigolo et al. (2018) identify socioeconomic demographics, attitude towards technology, awareness about the risks of using traditional cooking stoves (TCS), and perception of benefits of using improved cooking stoves (ICS) plus location-specific cultural influences as critical factors influencing cooking choices. Several studies have also reported on the socioeconomic factors that potentially influence both the choice and the adoption of ICS. Rai and Robinson (2015) used applied agent-based modeling to delineate how social, behavioral, economic, and environmental factors influence the adoption of any new energy technology like ICS. Substantial insights could also be gathered from the study carried out in the context of Peruvian rural families, where social capital has been observed to play a critical role in the transition process from TCS to ICS (Adrianzén, 2014). The study observed that when community bonding is strong, and many beneficiaries within the community are going through usage and adoption problems, the trust or social capital created through community bonding tends to influence and reduce the individual usage probability of ICS. Usage problems of rural families in the Peruvian Andes case mainly were related to faulty stove materials. Furthermore, constraints related to the availability of credit for families and the liquidity of families to pay back the credit loan can also delay the introduction, adoption, and sustained usage of new and improved cookstove technologies by rural families. This can also hinder the transition of rural families from firewood, cow dung cake to ICS (Banerjee, 2003).

The relevant literature that explored the socioeconomic determinants and drivers behind rural energy transition from TCS to ICS also underscores the nature and extent of social interaction as a significant trigger enabling such rural energy transitions in cooking choices. The

social interactions facilitate the communication of any change in behavioral dynamics of rural families through social networks. (Axsen & Kurani, 2012). These networks enable the diffusion of information across social groups and help in conformity to others' behaviors. Organized and resourceful social groups facilitate the dissemination of information to promote social bonding.

In this context, the illustrations could also be drawn from the North Indian state of Himachal Pradesh, where the underlying social processes that include community politics, social identity, and perception about cleanliness impact the decision of TCS to ICS adoption (Wang & Bailis, 2015). Some studies also identified social networks and gender-based diffusion of information as crucial for a rural energy transition from firewood to ICS (Ramirez et al., 2014; Kumar & Mehta, 2016).

Other factors like market-oriented approaches that can make the energy market accessible and attractive to local investors, communities, and consumers and improve access to devices like ICS for cooking for rural and poor people can enable the transition process (Barnes & Floor, 1996). Furthermore, the type of fuel and technology used in a stove define thermal efficiency, i.e., cost of operating) and operational convenience. Awareness and family structure (family size, age, and gender, willingness to adopt new technology, economic status) affect the adoption of ICS (Bielecki & Wingenbach, 2014; Shen et al., 2015). The transition decision in low-income countries could be influenced by product price, family income (Beyene & Koch, 2013), product attributes, market segmentation (Jeuland et al., 2015), poverty, gender empowerment, regional coverage, policies (Kumar & Mehta, 2016), business models including design, customers targeted, financing, marketing, channel strategy, and organizational characteristics (Shrimali et al., 2011).

The key benefits of using ICS are health improvements and environmental protection

from the reduction of CO₂ emissions. Rosenthal et al. (2018) estimated the health and environmental benefits through CO₂ emissions reduction across a diverse group of 40 Low Middle-Income Countries (LMICs). The findings indicate that LPG stove adoption by rural families in LMICs will lead to a significant reduction in Disability Adjusted Life Years (DALYs) and CO₂ emissions. Similarly, Johnson et al. (2019) found that switching from TCS to LPG stoves and forced draft stoves (Oorja and Eco-Chula) reduces indoor air pollutants. Purohit et al. (2002) used a metadata-based model to show that ICSs save 550 million tons of CO₂ annually and have significant health benefits. Pattnaik et al. (2019) surveyed 1000 families for transition to ICS. They found that the demand for transition to ICS will increase with proper supply chain management that addresses local needs. Clean energy for cooking improves the quality of life by providing more time for other activities, improved work outputs, and reduced health costs. Improved access coupled with sustained adoption and usage of ICS can help the rural families create avenues for new income generation and services for themselves and the local economy (Kemmler, 2007; Stern 2014). The energy service generation can improve further if the ICS is integrated with heating and lighting devices. This holds good particularly true for ICS that runs on electricity. An electric ICS with charging and lighting points can enable a smoother transition from TCS to ICS for rural families in low-income countries by facilitating access to a package of energy-related services (Dhoble and Bairiganjan, 2009). Such transition and associated quality of life improvement were reportedly in low-income countries like India (Bhattacharya and Salam, 2006); Peru (Adrianzén, 2014); Nepal (Singh, 2012); and Thailand (Limmeechokchai and Chawana, 2007).

Coming to the impediments in rural energy transition, a large number of studies have identified the prevalence of cookstove and fuel stacking, i.e., the use of multiple devices and

fuels to satisfy family cooking energy needs as an impediment in the transition process to ICS in developing countries (Masera et al., 2015; Piedrahita et al., 2016). The main factors for the transition from TCS to ICS in West Africa are family size, applications of cooking stoves, the total mass of wet and dry ingredients, the use of embers as an igniter, and the number of fires used in cooking (Johnson & Bryden, 2012). The study by Johnson and Bryden also mentioned that designing solutions to meet these transition needs from TCS to ICS requires understanding the human, natural, and engineered systems that drive the particular village energy dynamics. The following subsection provides insights on energy consumption for cooking in rural Indian families across different income classes.

1. Energy consumption and energy transition for cooking in rural India

According to the latest Census Report of India, 87 percent of the rural families and 26 percent of the urban families depend on biomass for cooking (Bandyopadhyay et al., 2019). A program (Unnat Chula Abhiyan) to promote ICS and transition to cleaner energy in cooking in rural India was started in 2014. However, the adoption of these ICS has remained low. Reasons for a low adoption rate of ICS include higher user expectations, low awareness, low perceived benefits (Mobarak et al., 2012), inadequate management of supply chains, and a lack of promotion (Arun, 2015). Per capita, monthly consumption of firewood and LPG in rural India is 29.50 kg and 2.31 kg, respectively (National Sample Survey Office, 2010). The low consumption of LPG is due to its relatively high price. Access to forests and the low cost of the collection make the sale and use of firewood financially viable (Bošković, B., Chakravorty, U., Pelli, M., & Risch, A., 2018). The opportunity cost of saving time from using LPG in rural areas is low. So, the use of LPG in rural areas becomes financially disadvantageous. This creates a barrier to the

adoption of LPG in rural areas. An alternative to reduce the prices of LPG to rural consumers is through efficiency improvements or a subsidy. The Government of India launched another program (Ujjwala Yojana) in 2016 to distribute LPG stoves without any cost to consumers to reduce the environmental and health impact of using TCS. One hundred 100 connections were distributed to rural families under this program.¹

Per capita monthly expenditure in rural India ranges from INR 200 – INR 1200 (USD 2.80 to 17) (National Sample Survey Office, 2010). Families are classified based on income levels as low, medium, and high.² In low-income families, firewood consumption per month increased from 95 kg per month in 2000 to 102 kg in 2010. The firewood consumption for middle-income families increased from 107 kg per month in 2000 to about 125 Kg per month in 2006, followed by a decline to about 115 Kg per month in 2010. However, firewood consumption in the high-income group increased from about 112 kg per month in 2000 to about 120 Kg per month in 2010. The overall increase in firewood consumption between 2000 and 2010 is around 7.4 percent, 7.5 percent, and 7.1 percent for low, middle, and high-income families, respectively. Firewood in rural India is entirely used for cooking because it has no other purpose.

Although the increase in firewood consumption over the years has been similar, per capita consumption indicates that firewood consumption comprises a large part of expenditure for low-income families and a very small part of expenditure for high-income families. Furthermore, the income elasticity of consumption for cooking fuels is also expected to differ between low and high-income families (Srivastava et al., 2012).

¹ See <https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1525934> (last accessed 08 May 2020)

² Expenditure is used as a proxy for income of household.

No income group indicated a rise in the consumption of LPG during this period. However, the usage dropped between 2006 and 2010 (National Sample Survey Office, 2006; 2010). The same consumption of 6-8 kg per month has been observed for low-income families. Both medium and high-income families have been found to consume around 10 Kgs per month (National Sample Survey Office, 2010, 2006, 2000). A 14 kg LPC cylinder lasts for four to five months in a low-income family, two to four months in a middle-income family, and 1 to a little more than two months in a high-income family. This translates to two to three LPG cylinders per year for a low-income family, three to four cylinders for a middle-income family, and four to six cylinders for a high-income family for a complete transition to clean cooking. Due to the supply chain constraints and the cultural preferences of rural families, the demand for clean fuel for cooking is not met. Other than LPG, rural family cooking demand had to be met through alternatives like ICS with better combustion efficiency to reduce the dependence on firewood or biomass. The dependence of rural families on fuelwood/biomass for cooking continues due to the lack of a reliable alternative. These findings corroborate the earlier empirical research findings (Sehjpai et al., 2014; Balachandra, 2011; Pachauri et al., 2004).

Nevertheless, there is an effort to replace firewood with cleaner fuel. IEA (2019)³ indicates a reduction of ten percentage points in India's share of population relying on biomass and kerosene between 2010 and 2015 for cooking. Most of this ten percentage points drop in the share has come due to rural families switching to LPG for cooking.

This paper analyzes the cooking-energy transition process at national, state, and district levels. Further, it determines the drivers of transition in cooking- energy, benefits from the transition to cleaner energy, and impediments to the transition in different countries. The paper

³ <https://www.iea.org/reports/sdg7-data-and-projections/access-to-clean-cooking>

also examines the similarity of these drivers at national and sub-national levels. The paper revisits the conventional energy ladder hypothesis for cooking energy transition for rural families in India.

2. Research Methodology

This section is divided into two sub-sections at the national and sub-national levels. The national-level analysis involves constructing an econometric model and examining the variables/drivers that potentially influence the probability of a switchover from firewood to a modern fuel. Bihar (state) has been selected for the case study at a state level. Bihar is growing economically, but it still uses traditional sources of energy for cooking. For the district level analyses, 38 districts of Bihar have been selected.

3.1 National-level analysis

A meta-analysis of the literature on applications of modeling techniques to examine and explore rural energy transition reveals that the family characteristics across different income groups tend to influence rural energy transition. Only a few peripheral factors influence rural energy transition for cooking in rural families (Van der Kroon et al., 2013). An empirical exercise using a multinomial logit model has been conducted to examine the transition process in cooking energy. The data used in the analysis is from the 66th Round of NSSO. The model is at the family level and has more than 83,000 observations. A binary choice of fuel (firewood or alternative clean fuel) is provided in the model. The dependent variable in the model is the primary cooking fuel used by rural families. Switching from firewood to LPG is considered transition. However, the use of ICS, kerosene, and biogas are considered intermediate stages of

transition.

Various explanatory variables have been identified from the literature as potential influencers of change to clean fuel options (Table 1). Amongst the independent variables, access to the internet has been chosen as an all-encompassing proxy for access to current information that subsumes all other technological access under it. Access to information through the internet is also expected to empower families with information that potentially influences better realization of their quality of life and livelihood.

<< Insert Table 1 here >>

The multinomial logit model uses the cumulative distribution function, specified as below:

$$F(l) = P(L \leq l) = 1 / (1 + e^{-l^4}) = (e^l / (1 + e^l)) \quad (1)$$

Hence the equation specification of the model comes out to be as

Predicted Logit (lfp=1, 0) (choice of primary cooking fuel)

$$= \alpha + \beta_1(mpce) + \beta_2(district) + \beta_3(internet) + \beta_4(regsal) + \beta_5(hh) + \beta_6(cv) + \beta_7(stat\ reg) + \beta_8(rel) + \beta_9(socgrp) \quad (2)$$

Predicted Logit (lfp=1, 0) (choice of primary cooking fuel) =

$$\alpha + \beta_1(cv) + \beta_2(stat\ reg) + \beta_3(rel) + \beta_4(socgrp) \quad (3)$$

Within the dependent variable, clustered samples are created. Within these clustered samples, fixed effects of the explanatory variables on the dependent variable are checked. For every sample, a maximum likelihood estimator convergence test is carried out. The estimators are finalized after the maximum likelihood test-based estimators are observed as complying with the

⁴ Logit (p) = log (p/(1-p)) = log (e^l/1 + e^l/1 - { e^l/1 + e^l}) = log(e^l) = log (e^{α+β₁(mpce)+β₂(district)+β₃(internet)+β₄(regsal)+β₅(hh)+β₆(cv)+β₇(stat reg)+β₈(rel) + β₉(socgrp)}

reliability range per the multinomial logit model simulation for the clustered samples of the different rural families. As a part of the simulation exercises involved in the process, some of the explanatory variables for specific clusters usually get dropped to create a maximum likelihood test-based estimator. The variables are dropped primarily to eliminate the possibilities of multicollinearity within the independent variables. The dropping of the variables occurs through an automated software-based simulation program embedded within STATA software that has been used here to carry out the exercise. Within the simulation process, a cluster-based approach is applied. For every cluster, the simulation is conducted, and the maximum likelihood estimator of every cluster is estimated. A convergence test of the maximum likelihood estimator with the corresponding probability values and other statistical parameters is also done.

A group effect analysis has been conducted purposely to understand and contextualize the impact of social and cultural norms of a village society on rural cooking energy transition in India. In the rural energy transition literature, as already discussed, belonging to a particular culture, group, or community often decides the rural energy transition from firewood to the adoption of ICS in a sustained way (Akintan et al., 2018). Culture, identity, group lineages can influence the improved cookstove adoption behavior of rural families. Hence, analysis of group effects as a part of the econometric model is critical in the context of this research.

In the national level econometric modeling exercise, the base outcome is that families select firewood, and the alternative outcome is that they select other fuel options, including LPG. Therefore, the value of $Y=1$ represents the choice of firewood by the rural families for cooking and $Y=0$, otherwise (which means usage or choice of other clean cooking fuel options like LPG or biogas for cooking by the rural families). Furthermore, cooking devices like integrated ICS are used interchangeably with clean cooking options primarily used by families that are still

dependent on firewood as a primary fuel for cooking. The analysis is validated by a Likelihood Ratio (LR) Test and the associated Chi-Square values.

3.1 Methods for sub-national analysis: digging down to an energy-poor state

An exploratory analysis has been carried out at a sub-national level to identify the state-level factors that may potentially influence the chance of transition to cleaner cooking options. In order to do so, an analysis of the level of income and energy consumption by rural families has been carried out. The analysis is based on data from the 66th Survey of NSSO. Three income classes have been constructed from INR 200 – INR 1200 and beyond based on the MPCE in the states from the sampled data. Correspondingly for each income class, monthly fuel consumption in terms of Kcal was estimated. With the energy poverty benchmark of 629 Kcal of energy consumption per capita per month (Srivastava et al., 2012), an assessment was done to determine which state of India has the highest amount of energy-poor rural families. The energy consumption has been calculated based on total fuel consumption multiplied by the conversion and fuel efficiency by taking a standardized, harmonized conversion factor for every cooking fuel option. From the analysis, it turns out that that the state of Bihar is one of the most energy-poor states and was subsequently selected to conduct a case study here. Bihar is lagging in terms of transition to clean cooking options due primarily to the concentration of low-income population within the state. The situation is compounded by broad social and cultural diversity within the state. Based on the analysis of the data from the 66th round of NSSO, an average rural family of Bihar has been observed to consume 60 kg of firewood and 120 Kwh electricity per month as compared to the national average of monthly consumption of firewood that ranges between 40 to 43 kg and electricity consumption of 644 kWh in the same year. A rural family in

Bihar consumes 2.53 liters of kerosene per month compared to the monthly national average of 0.51 liters. A rural family's monthly average LPG consumption in Bihar is 0.93 kg against the national average monthly consumption of 7.7 kgs.

3.1.1 Computation of Atkinson's Energy Inequality Index

An energy inequality index has been constructed from the energy consumption for select states to understand the inequality in energy consumption. The inequality measure that has been used here is the Atkinson index (also known as the Atkinson measure of inequality). It is a measure of inequality that helps determine which part or segment of a specific distribution leads to an observed inequality (Schlör et al., 2013; Du et al., 2015). Atkinson index is used to a large extent in understanding inequality in the process of social distribution (Cowell, 2000). In this paper, inequality is examined in the case of final energy consumption.

The index is defined as below –

$$A_{\epsilon}(E_1, E_2, \dots, E_N) = 1 - 1/\eta \left[1/N \sum_{i=1}^N (E_i)^{1-\epsilon} \right]^{1/(1-\epsilon)} \text{ for } 0 \leq \epsilon \neq 1 \quad (4)$$

Here η is the mean value of final energy consumption, and $E_1, E_2, \dots, E_N$ are the energy consumption of the various income classes. In this case, there are N income classes. Therefore, E_i is the value of the energy consumption of each class. Dividing the total energy consumption value by all the classes by the total number of income classes (N) gives the average energy consumption of a single representative class. ' ϵ ' represents fairness or inequality aversion parameter (Sen, 1970) and shows how the average energy of a representative class is distributed across the income classes. The parameter is thus used to assign the degree of distribution of the energy across the different income classes. Hence, in the context of studying energy inequality for an energy-poor state like Bihar, ϵ can be used to weigh the energy consumption by various

income groups. The value of ϵ or the inequality aversion parameter can increase or decrease based on how we want to address the gap between the normative goal of attaining equity in terms of energy consumption and the actual inequality that exists in the same.

When $\epsilon=1$, the inequality index becomes-

$$A_{\epsilon}(E_1, E_2, \dots, E_n) = 1 - 1/\eta \left(\prod_{i=1}^N E_i \right)^{1/N} \quad (5)$$

The index varies between 0 and 1 and measures the amount of social welfare that could be gained when there is a fair and equal distribution of energy across all income classes. In this paper, fairness is considered in terms of the distribution of energy consumption amongst different rural families of Bihar, which are not homogenous and are progressing in varying ways.

It is also assumed here that the social utility and hence welfare of a particular income class is a function of the energy consumption and income. Income has been measured through the proxy of monthly family per capita expenditure, which has also been used to create income classes. Correspondingly, the final energy consumption of these income classes from cooking fuels has been calculated. As a part of this process, 54000 data points were studied from the NSSO 66th round sample data for Bihar, which pertain to various districts of Bihar. From these data points, income classes were constructed based on the monthly per capita expenditure of the families. For every income class, their monthly per capita fuel consumption for cooking was estimated. The fuel options considered are – firewood, biogas, LPG, kerosene (as per the NSSO classification of 66th round). Then using the average end-use efficiency figure for cooking, the final energy consumption has been calculated.

3.1.2 Test for perceived nonlinearity in the energy transition

In addition, for the income classes, as already mentioned in the beginning, the pattern of

energy consumption for cooking across the districts of Bihar has also been analyzed and mapped against the district-specific average monthly per capita expenditure considering the number of families assuming the average family size of four.

In order to assess the perceived nonlinearity in energy transition for cooking fuels statistically, a district-level analysis has also been carried out for Bihar by using the Brock-Dechert-Scheinkman (BDS) test (Brock et al., 1991; Brock et al., 1996) for firewood consumption of energy-poor families selected from 38 districts.

The test originally developed by Brock, Dechert, and Scheinkman (1987) is considered the most popular test for nonlinearity. It was designed to test the null hypothesis of independent and identical distribution (iid) of a series to detect non-random chaotic dynamics. It can also be used as a misspecification test when applied to the residuals from a fitted model. In particular, when applied to the residuals from a fitted linear time series model, the BDS test can be used to detect dependence and the presence of omitted nonlinear structure. If the null hypothesis cannot be rejected, then the original linear model cannot be rejected; if the null hypothesis is rejected, the fitted linear model is misspecified. In that sense, it could also be considered a test for nonlinearity.

The statistic uses the correlation integral of the residuals of a time series observation within a nonlinear system. It examines the probability that a random, nonlinear system could have the same scaling properties. The statistic attains a standard normal limiting distribution under the null hypothesis of independently and identically distributed data (Akintunde, 2015; Lebaron 1997). In the paper, the BDS value of time-series observations of firewood consumption for different village units of Bihar from the Census Data of 2001 and 2011 have been studied. The detailed explanation of calculating the BDS value is as follows:

- a. A value of embedding dimension with m dimensional vectors is selected by selecting 'm' consecutive points in a series. Therefore, the series of scalars gets converted into vectors with overlapping entries such as

$$x1m = (x1, x2, \dots, xm)$$

$$x2m = (x2, \dots, xm+1)$$

- b. A correlation integral is computed. This measures the spatial correlation among the points through the addition of the number of pairs of points (i,j) , where $1 \leq i \leq N$, $1 \leq j \leq N$ in the m dimensional space and are close in the sense that the points are within a radius of ϵ of each other and mathematically can be expressed as:

$$C_{i,m} = \{1/(N_m * (N_m - 1))\} \text{ (summation of } I_{i,j}) \quad (6)$$

$$[\text{where } i \text{ is not equal to } j \text{ and } I_{i,j} = 1 \text{ if } \text{Mod}(x_{im} - x_{jm}) \leq \epsilon \text{ or } = 0$$

otherwise]

If the time series is independently and identically distributed, then

$$C_{\epsilon,m} \sim [C_{\epsilon,1}]^m$$

- c. If the ratio N/m is greater than 200, then the values of ϵ/σ range from 0.5 to 2, and the values of m are between 2 and 5; the correlation integral of m scalars has an asymptotic normal distribution with zero mean and a variance $V\epsilon,m$.

The correlation integral is then computed for the firewood consumption data of different villages of Bihar over time. The threshold statistics value for any set of observations in which BDS is applied is 1.96. If for any set of observations within a nonlinear dynamic system, the BDS value is above 1.96, it applies that the data is nonlinear and nonparametric.

3. Findings and Analysis

3.1. *Findings On National Level*

Tables 1(a), 1(b), and 1(c) highlight the results of how various context, location-specific variables like social group, community impacts the probability of transition to clean fuel/cooking options like biogas and LPG (denoted as Y).

Insert Table 1a

Outcome Table 1

Insert Table 1b

Outcome Table 2

Insert Table 1c

Outcome Table 3

The choice of cooking fuel is significantly related to the use of firewood, chips. It is also significantly impacted by the regular salary of families and rural families' marginal per capita expenditure. It indicates that the higher the calorific value of fuelwood, the smaller the chance of switching to alternative fuels. The higher the per capita expenditure, the larger the chance people switching to alternative fuels from firewood. This means that the chance of people in rural families in India switching to LPG from firewood is statistically significant and dependent on the marginal per capita expenditure of the rural families. Marginal per capita expenditure of families is nothing but a reflection of the constrained priorities of the family for a given liquidity and savings in the family. Thus, the attitude and perceptions of families regarding their development

and expenditure priorities have an essential role in choosing the primary cooking fuel, which can decide the probability of rural families' transition from firewood to other modern cooking fuels. A family may have the disposable income to spend on LPG. However, unless it perceives that the use of firewood has significant health impacts for them, the switch to cleaner fuels will remain to be realized and felt. Repeated simulation runs are conducted to highlight the impact of an explanatory variable on the dependent variable.

Outcome table 1 indicates that the types of the district and geographical locations (denoted by the belonging to a community and social groups) have a positive and significant impact on the use of all cooking fuels except the cooking fuel arrangement. Better the economic and developmental state of districts more prominent is the chance of switching of rural families from firewood to other alternative fuels for cooking. This posits that the chance of people switching from firewood to coal, LPG, biogas, dung cake, charcoal, kerosene, electricity, others is dependent on the type of activities happening in a district (as the district index is a composite index of economic, financial, trade, agriculture and other activities in a district). These activities can vary from location to location based on the remoteness of the district from the nearby town.

The fact that geographical contexts determine fuel switching reflects not just natural resource availability such as forests but also the state policies and their actual level of implementation. The positive coefficient indicates that better policy making and implementation will go a long way in determining fuel switching and family energy choices.

Table 1b indicates that the higher the prosperity of rural families in terms of their religious grouping, social group status, family size, the more significant is the chance of switching from firewood to other alternative fuels for cooking. Belonging to a particular social group (which can decide the trust levels) and type of institutions (which can decide the nature

and degree of social capital) can impact the probability of transition from firewood usage for cooking to other modern forms of fuel for cooking like - LPG.

However, another round of checking is done to cross-check whether the larger transition of rural families also impacts the rural energy transition in cooking through access to lighting choices. For this, it is analyzed whether access to modern forms of energy choices like electricity can bring in a developmental change in rural families and whether that can impact their energy choices in terms of cooking. Access to electricity and lighting can bring more information to rural families and make them aware of the long-term advantages of clean cooking practices. This can thereby impact the probability of the transition of rural families from firewood to other modern forms of cooking. It is also dependent on the type of a rural family. Here, the type of family is defined and seen through a composite index of family asset holdings, land, consumer durables, etc. Therefore, the capital assets and status of the families do make an impact in terms of their access to lighting which also thereafter affects the probability of the transition from firewood to modern fuel for cooking. This is also because the higher the index value of the family type, the greater the families' prosperity. They are better positioned in the developmental ladder of rural society. Hence, these families with higher index values can switch to modern forms of fuel for cooking from firewood. Therefore, this informed decision-making impacts the probability of the transition of rural families in a statistically significant way.

All the above observations are broad findings of the macro-econometric model to understand the association between the socioeconomic domains of rural families and their energy transition for cooking. This also needs to be supported by micro-level state-specific findings to

join the macro-level dots with the local micro-foundation contexts.

Table 1(a), (b), and (c) clearly shows that keeping other variables as controls, family size, community identity and monthly per capita expenditure does have an impact on the probability of switching to a cleaner cooking choice. This validates the importance of local-level factors in the process and probability of transition to cleaner fuels for cooking. The finding also substantiates corresponding intuitions drawn from the literature, as already elucidated before.

To further assess the impact of local-level factors which are exogenous to a family, variables representing community identity and social group are randomized. In contrast, other variables like monthly per capita expenditure, family size are kept as controls (as the families themselves can decide them). This exercise has been carried out to understand how the different family-specific and/or external factors eventually impact the switchover/transition to cleaner fuels.

Table 2 further shows that district type, location, and belonging to a social group also positively and significantly impact the chance of fuel switching. The district dummy is cumulative and captures the impact of the district across space and time. The table also shows that the choices of the cooking energy are affected by the presence of social groups and calorific value (denoted as cv here) of the fuel used by rural families. It indicates that higher the calorific value of fuelwood smaller will be the chance of switching to alternative fuels (Purohit et al., 2002) as higher calorific value results in more efficient cooking (assuming no variation in the cooking end-use devices or medium).

<<Insert Table 2 about here >>

The calorific value of the fuel (cv) can get enhanced in two ways – a) by using better-quality firewood containing less moisture, assuming that the combustion efficiency of the end-use appliance remaining unaltered, and b) by enhancing the combustion efficiency of the end-user device. This also, however, essentially implies that an enhancement in the resource input quality (say better quality firewood) may potentially end up disincentivizing or impeding the process of shifting to a new cooking device, say improved cookstove or to modern cooking fuel option like LPG for the same set of rural families. Furthermore, with a limited quantity of monetary resources available and competing demands from family budget, the risk-averse rural family will be more likely to prefer the improved quality of firewood than investing money in procuring new fuels or new appliances like ICS.⁵

As indicated in a more recent study (Pattanayak et al. 2019), the chance of switching to cleaner cooking options gets enhanced by relaxing the income and liquidity constraints in rural families.⁶ This could also be potentially influenced by the degree of conviction in decision-making for a particular rural family. For instance, a family head's conviction about a clean fuel and its impact on health outcomes can influence the decision-making to switch to a cleaner cooking fuel option by a rural family (Goswami et al., 2017). This also depends largely on how the family head is discounting the future benefit streams arising from the health benefits of using clean cooking *vis a vis* the liquidity constraints of the family (Morrison, 2014). In sum, and as already evinced by the literature, the demand for these improved energy technologies goes up

⁵ The model assumes that on the average most of the rural families that are using a firewood oven has a standardized combustion efficiency of around 30% (see <http://www.fao.org/3/AD585E/ad585e00.pdf>)

⁶ <https://www.pnas.org/content/116/27/13282.short>

when – 1) supply chains are robust; 2) technologies match local needs and expectations; and 3) income and liquidity constraints are relaxed.

To check for reliability of the model results, likelihood tests of the above estimators have also been carried out for a total data observation of 63,061 and reported in Table 3.⁷ The probability and likelihood value indicates that the estimates of the above model are robust and reliable.

⁷ The optimality and convergence are achieved by reaching to the specified number of observations i.e.

<< **Insert Table 3 about here** >>

All the three variables related to the quality of the fuel resources, namely location, type of the district, and whether family belongs to a particular community/social group and participation in a social network, may potentially influence the chance of switching to cleaner cooking options the rural families. The local level factors that influence the fuel switch of a rural family are also evident from the metadata-based literature (Kroon et al., 2013). Furthermore, districts' better economic and developmental prospects also tend to influence the chance of switching rural families from firewood to other alternative fuels for cooking (Burwen & Levine, 2012). In addition, decentralized policies and levels of access to resources⁸ at a family level also often drive the transition to cleaner fuels for cooking (Srivastava et al., 2012). In other words, implementation of progressive policies at the ground level may potentially improve the chances of switching to cleaner fuels in the future. All these possible relationships in rural family energy transition have been examined and reported in Table 4.

Insert Table 4 here

Table 4 indicates that the characteristics of rural families defined by their religious grouping, social group status, family size can impact the chance of switching from firewood to other alternative fuels for cooking. The district dummy is a default control factor for both Table 2 and Table 4.

⁸ Level of access depends on whether the rural household has the ease/difficulty in access to fuel i.e., firewood collected either from the forest or from elsewhere around the household.

As above, to reinforce the findings, it would be worthwhile referring to a detailed study of 24 African countries carried out by Asongu et al. (2016). Using a panel autoregressive distributed lag models, the authors demonstrated that with economic prosperity in the long term, the transition to clean fuel options can happen in cooking. However, economic prosperity does not usually come from income alone but also from the freedom to live the life one wants by developing the required capabilities, which finally generates income as elucidated in the capability approach pioneered by Amartya Sen (Sen, 1999), which talks about functioning (actual beings and doings by people) and their capabilities. In other words, economic prosperity is also primarily linked to access to basic essential human development needs.

For instance, access to lighting can potentially initiate a chain effect by facilitating the generation of economic services (Kanagawa & Nakata, 2008). The generation of economic services can, in turn, enhance the quality of life and could potentially influence the family decision on switching to clean fuels like biogas or LPG for cooking. Interesting research carried out by Morley et al. (2018) and Jha (2013) shows how peak electricity demand can be impacted with digitization and larger internet penetration in rural areas, indirectly affecting rural families' lighting demand. According to them, everyday practices are constantly changing in rural families of developing countries due to internet-related energy consumption and policies. So, does the influx of digitization and access to information through multiple electronic gadgets also generate the possibility of rural families making improved choices when it comes to energy for cooking? That question is being explored here.

Over the last decade, India has witnessed an exponential growth in the internet and access to the worldwide web (www), even in rural families, due to the influx of electronic gadgets and mobile telephony. Hence, the possibility of access to information eventually impacting the peak

demand for lighting cannot be completely ruled out. However, such perceived chain effects through transmission from reallocated demand for lighting by rural families to the adoption of clean cooking fuels or clean cooking choices clearly needs empirical and statistical validation. Otherwise, irrespective of whether the coupling happens or otherwise, the availability of the internet is also expected to empower families with information that could potentially influence better realisation of their quality of life and livelihood and make a better-informed choice with a potential implication on the choice of fuel for cooking. The availability of the internet usually comes through devices like mobile, computers, etc. Therefore, the availability of the internet has been chosen here consciously as an all-encompassing proxy to carry out the empirical validation of any influence/impact of the availability of internet on cleaner forms of cooking. The results are presented in Table 5.

<< Insert Table 5 about here>>

The table indicates that the access to information through the availability of the internet may not significantly influence the choice of cooking fuels for rural families, ruling out the possibility of any potential coupling of the reallocated demand for electricity with that of cooking choices.

4.2 Findings On Sub-national Level

4.2.1 Estimate of Energy Inequality

The energy inequality is estimated for states like Madhya Pradesh, Bihar, Odisha out of the five most energy-poor states - Madhya Pradesh, Bihar, Odisha, Rajasthan, and Uttar Pradesh. These states have been chosen as the highest number of rural families lie below the

benchmark/threshold of energy consumption of 629 Kcal per capita per day benchmark.

The inequality in firewood consumption has been marginally higher in Bihar than in other energy-deficient states like Odisha, possibly due to more accessible access to forests for those residing in Odisha (Table 6). Balachandra (2011) also highlights that Bihar and Odisha are the most energy-poor states in India when considering energy consumption. Sadath and Acharya (2017), in a paper using a multidimensional energy poverty index, highlights Bihar as one of the most energy-poor states of India. The most recent findings using the multidimensional energy poverty index (Gupta et al., 2020) also tallies with our energy poverty estimates considering the different rounds of NSSO sampled data.

Table 6 below shows that a higher energy-poor state like Bihar in comparison to Odisha also shows a high level of energy inequality in a primary fuel for cooking like firewood compared to Odisha. The energy inequality of Bihar in firewood for cooking is 0.38 in comparison to 0.33 in Odisha. A higher energy inequality can also lead to a rise in income inequality. Bouzarovski et al. (2017) showed through a spatial and temporal analysis how a rise in energy poverty coupled with energy inequality in Southern and Eastern European states also led to an increase in income inequality by increasing the inability of a rural family to get access to quality energy services at home and meet their much needed social and material needs. As discussed in the paper, a substantial part of the energy inequality arose from the cooking energy component, followed by lighting and space heating.

In the current exercise, albeit in the context of an energy-poor state, it could be observed that higher energy inequality in primary fuel for cooking (firewood) and energy poverty also shows a higher income inequality.

<<Insert Table 6 about here>>

Results of the model tend to indicate that the chance of switching to a modern cooking fuel like LPG is impacted by the income of rural families (proxied by mpce) and fuel quality for a state. Nevertheless, it would be worthwhile digging down further to the district/village level to understand whether income really turns out to be the key driver or if the perceived linearity between income and fuel consumption as prescribed by the energy ladder hypothesis continues to hold good. To examine the same, the paper takes up 36 districts of Bihar, which comes out as one of the most energy-poor states. As per the NSSO 66th round, the mpce of some districts of Bihar has also been observed to be the lowest among the districts across all the states of India.

4.2.2 Findings at the District Level on Perceived Non-linearity

Figure 1 delineates a possible presence of nonlinearity in the relationship between firewood consumption and income at the district level and, in a way, complements/reinforces the findings in Section 4.1. It depicts that some districts with a high average value of monthly per capita expenditure (the blue line) show low energy consumption. The observation hints towards possible usage of firewood as primary cooking fuel even in the high-income earning district. Hence, higher income facilitating a transition of primary cooking fuel from firewood to LPG, eventually leading to higher energy consumption, does not hold good in all districts of Bihar. Contrary to the conventional wisdom, fuel/ energy consumption has been higher for low-income districts than high-income districts.

<<Insert Figure 1 about here>>

Going by the energy ladder⁹ hypothesis (Kowsari & Zerriffi, 2011), development is expected to happen with rising income, assuming that an appropriate income distribution is in place, which, in turn, is expected to gear up further a new set of economic and developmental activities eventually leading to increase in energy consumption (Maconachie et al., 2009). This pattern has primarily been observed in industrialized and developed countries. However, this may not necessarily hold good (Niu et al., 2012). From a meta-analysis of the literature, it also emerges that even though socioeconomic family characteristics tend to influence the transition from firewood to modern fuel options like LPG, the impact does not appear to be a linear one as a country transitions from its developing country status to the status of a developed country, where the status is measured in terms of the income and other quality of life pointers (Kroon et al, 2013).

The pattern observed here also points towards that direction. It tends to indicate the possibility that income may not be the only key driver of energy consumption in rural families at the district level. Even if income happens to be a significant determinant or driver, other socioeconomic factors that are external/exogenous to the families could more than offset the income effect while driving the process of energy transition and in effect makes the dynamics of energy transition nonlinear.

The Brock-Dechert-Scheinkman (BDS) test carried out on firewood consumption of rural families from the 38 districts of Bihar to validate this perceived nonlinearity statistically shows the test statistic value exceeding "1.96", which is considered as a threshold, as indicated in sub-

⁹ The energy ladder shows the path of how when families move up in an income ladder in terms of their actual income or monthly per capita expenditure, the energy basket of the same household for cooking, lighting and space heating, cooking options move towards more modern forms of energy like LPG (from firewood for cooking), like electricity (from kerosene for lighting) and other modern household appliances for space heating/cooling options instead of using firewood for space heating

section 3.1.2. The BDS statistics value for firewood consumption for 1.2 crore rural families across 314 village units over 30 years appears to be between 4.06 and 4.50.

The BDS statistics for fuelwood consumption in the studied families over the time frame are greater than 1.96, which is the critical value of the statistics following the null hypothesis of no nonlinearity at a 5% significance level (or 95% confidence interval). The null hypothesis is rejected. It indicates that based on analysis of census data, Bihar is showing a spatial chaos pattern (which is a kind of nonlinear pattern) in fuelwood consumption across rural families for 30 years.

This observation thus also hints towards a chaotic/nonlinear pattern in the long-term firewood consumption data of the rural families chosen from the energy-poor districts of Bihar and reinforces the insights drawn from Fig. 1. The finding also complements the observations on the impact of district-level factors on choice of cooking based on multinomial logit models at the national level using NSSO data.

4. Conclusion

The paper revisited the problem of energy transition in the context of cooking in the rural family, which continues to be considered a weak link in the process of rural energy transition in India (IEA, 2019). The findings from the exercise using multinomial logic models coupled with an estimate of Atkinson's measure-based energy inequality at the state level and observation at the district level suggest the interplay of non-income drivers in influencing the choice of cooking options and tend to contest the more conventional wisdom rooted in the energy ladder hypothesis in the context of the rural energy transition for cooking in India. The findings from BDS test also cast doubt on the linearity in the relationship between income and energy transition at the district

level. Here linear means a proportionate causal association between families' income and shifting to a cleaner energy choice.

The results of the empirical exercise based on multinomial logit models and the group effects (fixed and random effects) carried out in this paper demonstrates the statistical significance of both individual family level variables (like location, district, family size, quality of fuels, liquidity) and group-level variables (like belonging to a social group/network, cultural norm, and community identity across different districts). The findings thus delineate the likelihood and significance of both individual and group-level factors in explaining the choice from firewood-based cooking to other alternative fuels or cooking options.

There is no second thought that transition to modern forms of cooking fuel choices from firewood to LPG, or devices like ICS or any other options depends to a large extent on the trust levels of community on new technology choices and local factors related cultural practices and beliefs embedded in cooking. The trust factor and hence social capital also happens to be context, community, and culture-specific and is determined by the nature, extent, and degree of information passed onto the rural family users about a fuel like LPG or new technology applications like ICS. That a rural family belongs to certain social institutions and networks like self-help groups can also often determine the nature, extent, and degree of information transmitted to rural families about these new technologies/ modern fuel. If the information comes from the self-help groups where the leader of the self-help group is of the same community, say, as of the rural family, the trust on the authenticity of the information about the benefits of new improved technology usage like ICS (improved cooking stove) for cooking tend to increase (Goswami et al., 2017).

From a meta-analysis of the literature, it also emerges that even though socioeconomic

family characteristics tend to influence the transition from firewood to modern fuel options like LPG, the impact does not appear to be a linear one as evinced by a country's transition from developing to a developed status, where the status is measured in terms of the income and other quality of life pointers (Kroon et al, 2013). This pattern also hints towards the possibility that income may not necessarily be the key driver of energy transition in rural families. Even if income happens to be a significant determinant, other socioeconomic factors that are external to a rural family could more than offset the income effect while driving the process of energy transition and make the dynamics of rural energy transition for cooking essentially nonlinear and, in effect contesting the energy ladder hypothesis that presumes a linear path of the energy transition with the growth of income. The finding is in line with an earlier contestation of the energy ladder hypothesis in cooking energy transition by Masera et al (2000). Masera et al. (2000), in the context of their study in Mexico, demonstrated that the fuelwood rarely got replaced completely, even in families that have been using LPG for years. Fuelwood was still considered essential for tortilla making in Mexico—both for technical and cultural reasons. What was striking in the study was that they observed that multiple fuel users were even willing to pay a "premium" for continuing to use fuelwood. In a village level study for the state of Bihar, Goswami et al (2017) also observed that the local culture and preference for a firewood-cooked chapatti (Indian bread made out of wheat) tend to create a bias against the usage of improved fuel cookstoves or modern fuel like LPG. The study also observes that the social position/status decides how and what type of information flow happens between the families regarding the utility and benefits of usage of an ICS in a rural context. The results of the BDS test statistic hinting towards nonlinearity and findings from multinomial logit models are in line with the findings of Masera et al. (2000) and Goswami et al. (2017) and demonstrates the potential

presence of nonlinearity in the long-term firewood consumption data of the rural families chosen from the energy-poor districts of Bihar, which is chosen here as a case in point. Hence, it might be difficult to conclusively infer if capital or operational subsidy on LPG alone could make a significant difference in families' choice unless the non-income drivers are adequately factored in policy discourse and/or deciding on the policy instruments. The weakness in the link between income and energy transition has also been emphasized in a recent study by Sharma et al (2019). Another study by Kar et al (2019) based on LPG sales data also reinforces the family's continued dependence on solid fuel/firewood. It indicates a very low offtake of LPG cylinders per month. A follow-up study/paper by Kar et al. (2020) additionally reaffirms that a one-time capital subsidy on LPG may not be adequate to provide a big push to LPG.

In fine, the mainstream energy policy discourse that is built on a more linear path of the energy transition as embedded in the energy ladder hypothesis may not be able to identify the right kind of instruments appropriately or perhaps a mix of instruments that would be necessary to provide a big push to plug this weak link in the rural energy transition to modern sources of energy like LPG. The existing policy discourse needs to draw insights from potential factors causing the nonlinearity in the dynamics of energy transition when it comes to cooking and/or internalize the cultural, social, and community level fulcrum of family preferences. The social and cultural fabric determines the information flow dynamics as information flow tends to be smoother in specific social clusters and networks (Pentland, 2014). The energy policy discourse and implementation process on rural energy transition of India ought to be cognizant of these issues to make a broader impact and for enabling an unimpeded transition when it comes to cooking energy choices. Another important dimension that needs to be studied in detail is the perception of women on improved cooking fuels/options as women are the key decision makers

in Indian rural families when it comes to cooking. Therefore, further detailed research based on a more pervasive countrywide data set might be needed to analyze the relationship between women's choice of fuel use and their comparative perception of welfare arising from different cooking options and needs to be factored in the policy discourse.

India has secured the lion's share of the families electrified under the Saubhagya Scheme (India's national family electrification program)¹⁰. It is currently considered a feather in the cap of the ruling government. While universal electricity access appears within reach, recent IEA analysis clearly shows that under current trends, more than half a billion Indians will continue to lack access to clean cooking by 2030, with implications for health and lost opportunities for women (IEA, 2020). It is well established in the literature that focuses on the connection between energy and development that economic prosperity can come from access to lighting. It helps enable access to essential economic services and facilitates meeting the unmet needs of the rural community (Kanagawa & Nakata, 2008). This can potentially enhance the quality of life and may, in turn influence a family's decision to switch to clean fuels for cooking (Reddy et al, 2009; Reddy, 2015). Therefore, an additional exercise through an all-encompassing indirect proxy has been carried out in this paper using a multinomial logit model to examine the veracity of such coupling of rural electrification with cooking energy choices. The exercise takes cognizance that the demand for electricity is largely driven by the progressive increase in availability and access to the internet in rural areas. As per the recent survey report brought out by the Internet and Mobile Association of India, as of November 2019, the internet users in rural India have already been more than 10% more than urban India (IAMAI, 2020). However, the result/finding using internet availability as an all-encompassing proxy does not reveal any

¹⁰ <https://saubhagya.gov.in/>

statistically significant relationship with the choice of fuel for cooking. One of the limitations of the multinomial logit model adopted here for the study is its inability to capture the coupled chain effect-based feedback. This is critical because the nature of this transmission between access to lighting to clean fuel choice adoption and the coupled effect between them via economic service generation, quality of life improvement is simultaneous. Hence, a simultaneous equation model structure or a systems dynamic model framework could be more suitable to capture this coupled effect and is thus considered a future research scope.

A critical element that also needs validation in this context is the reliability and quality of electricity that comes to the family from the grid, as rural family electrification is primarily focused on grid expansion. NSSO data that has been used here contains no information on the quality and reliability of lighting. Hence no inference could be drawn to that extent on the indirect impact on cooking fuel choice. Therefore, the perceived influence of such an electrification process that could be potentially associated with the influx of electronic gadgets in villages on making other choices on improving the quality of life, including cooking energy choices, also remains unfounded. However, literature in other countries tends to indicate potential causality in that direction. Based on the analysis, the finding also indicates that rural families did not seem to alter their choice despite a progressive increase in access to information through the internet, or fuel stacking may prevail, even where there is access to ICS or LPG. After some time, the cultural assimilation of LPG in rural families requires further research to know the extent of transition.

Declaration

A. **Ethics approval and consent to participate** – All Authors abide by the Ethical Guidelines of the Publication and gives their consent to participate by following the ethical guidelines

B. **Consent for publication** – All Authors are providing the consent for Publications

C. **Availability of supporting data** – All Supporting Data will be made available

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Figures

Figure 1

Pattern of useful energy consumption across income classes within districts of Bihar **Final useful energy consumption doesnot include electricity. This includes the primary useful energy consumption like firewood, coal, gobar gas etc. Indirect derived energy like electricity is not a part of this estimate.