Seismic Shock and Household Fuel Choice: Evidence from the 2016 Earthquake in Uganda

Toshiki Obara[1]

51238046

Abstract

This paper examines the impact of an earthquake on household fuel choice using the example of the 2016 earthquake in Uganda with four Waves Uganda National Panel Survey (UNPS). Results from a difference-in-differences analysis indicate that households exposed to seismic shock are likely to reduce the number of fuels for cooking and increase relative reliance on firewood. The findings in this paper supports the existence of the left side of "inverse U" curve of Heltberg (2005)'s finding and imply that seismic shock may hinder the household energy transition.

[1] Graduate School of Public Policy, The University of Tokyo, obara-toshiki480@g.ecc.u-tokyo.ac.jp

0. Table of contents

1. Introduction

Among the 17 SDGs, SDG 7 states, "Ensure access to affordable, reliable, sustainable and modern energy for all[2]". For household-level energy transition, two indicators, i.e., "Proportion of population with access to electricity" and "Proportion of population with primary reliance on clean fuels and technology," are concerns related to SDG 7. However, according to THE ENERGY PROGRESS REPORT 2024 (IEA et al. 2024), estimated 79% of the population in Sub-Saharan Africa and 33% of the population in Central Asia and Southern Asia were still using polluting fuels and technologies for cooking. For this reason, developing countries seek a way to energy transition. For example, in Uganda with 88% of the population relying on biomass energy for cooking in FY2018/19, household energy transition, such as cooking fuel transition from biomass energy like firewood to clean energy like LPG and the increase in the proportion of the population with access to electricity, 91.7% of which is generated from renewable energy in FY2018/19 (hydro: 79.5% large and small plants), thermal plants: 8.7%, solar PV: 3.5%), until 2025, are listed as one of the goals of the Third National Development Plan (NDP III) (Uganda National Planning Authority 2020).

The use of biomass fuels can have some negative impacts on human health, the environment and economic development (Heltberg 2005). Indoor air pollution emitted from the use of traditional fuel and cooking stoves can cause serious illness (Duflo et al. 2008, Parikh et al. 2001). Women and children tend to spend the most time and effort cooking and collecting firewood and are therefore more vulnerable to the negative effects of biofuel use (Heltberg 2005, Van der Kroon 2013). Since the productivity of a person is proportional to his or her health status, the use of biomass fuels may restrict poverty reduction, economic growth, and long-term economic development. (Rao et al. 2007). Biomass fuel has also significantly contributed to increasing deforestation (Geist and Lambin 2002). According to UNEP, deforestation contributes to the increase in the emission of carbon dioxide through the following two channels[3]. Firstly, trees absorb carbon dioxide from the air in the process of photosynthesis, and stores carbon in their body, but when trees decay or are burned, they release stored carbon into the atmosphere in the form of carbon dioxide. Secondly, the loss of trees results in the decrease in absorption of carbon dioxide which they are to absorb in the future. As Van der Kroon (2013) claims, to overcome these negative effects, a transition in a

[2] "Ensure access to affordable, reliable, sustainable and modern energy for all", United Nations. https://sdgs.un.org/goals/goal7#targets_and_indicators (accessed 30th November 2024)

[3] "How halting deforestation can help counter the climate crisis", United Nations environment programme, 18th July 2024. https://www.unep.org/news-and-stories/story/how-halting-deforestation-can-help-counter-climate-crisis (accessed 8th March 2025)

household towards cleaner and more efficient fuel is needed and therefore the mechanism of household fuel choice is important to understand.

The energy ladder and energy stacking hypotheses partially describe household fuel choice. The energy ladder hypothesis assumes that as a household improves economic status, such as income, a household will move to more sophisticated fuels: from solid biomass fuels, such as firewood, animal waste, and crop residue, through more efficient but still polluting fuels, such as charcoal, kerosene, and coal, towards cleanest fuels, such as LPG, electricity, and biofuels (Schlag and Zuzarte 2008). While the energy ladder hypothesis assumes that a household perfectly substitutes one fuel for another in shifting, energy stacking hypothesis suggests that a household uses inefficient fuels simultaneously even when it starts to use more efficient fuels (Maseta et al. 2000). In addition to economic status, according to Van der Kroon et al. (2013), many factors are involved in household fuel choice and the factors can be distinguished into three categories: (i) the country external environment, such as climate, geographic location and history. (ii) household external and country internal factors, such as prices of goods, government policies, and consumer markets. (iii) household internal factors, such as human capital, household characteristics like gender, and cultural preferences.

A natural disaster can be one of the factors that influence household fuel choice because their shock will also influence other internal and external factors. The impact of natural disasters decreases household income and expenditure (Bui et al. 2014). To cope with the shock of disasters, households may spend less on education due to volatile income caused by disasters (Mottaleb et al. 2013). Disasters affect not only households but also infrastructures (Ghobarah et al. 2006).

Therefore, this paper hypothesizes that seismic shock can affect household fuel choice. An earthquake can affect the internal and external factors which determine household fuel choice and, in particular, can undermine the economic status of a household. Hence, a household affected by earthquake will climb down the energy ladder. In other words, the affected household will quit using transition fuels such as charcoal, kerosene, and coal, and advanced fuels such as LPG, electricity, and biofuels, and will rely more on primitive fuels, such as firewood, animal waste, and crop residue. This is because the transition and advanced fuels are often more costly than the primitive fuels and the affected household cannot afford to buy them.

Few articles focus on the impact of disasters on household fuel choice. Paudel (2023) examines the impact of the 2015 earthquake in Nepal on household fuel choices. The results of the difference in differences design show that households experienced large seismic shock are 40.83% more likely to use firewood as cooking fuel, decrease electricity expenditure, and are less likely to use gas cylinders for cooking purposes. The cause of the increase in the use of firewood is explained by the decrease in unit prices of firewood. The results also illustrate that households reduce consumption of electricity and kerosene for lighting in earthquake-affected districts.

The main objective of this paper is to investigate the impact of seismic shock on household fuel choices. It evaluates changes in outcomes related to fuel choice through the experience of exogenous seismic shock from the 2016 earthquake in Uganda employing difference in differences (DID) design. Specifically, it uses four Waves of the Uganda National Panel Survey (UNPS) conducted between 2013 and 2020 and compares household fuel choices for cooking and lighting, the number of fuels a household uses, access to grid electricity, and the ratio of ownership of solar panel between districts exposed to different levels of Modified Mercalli Intensity (MMI) before and after the earthquake.

The empirical results of DID indicate that the seismic shock from the 2016 earthquake has induced a significant decrease in the use of some fuels, Kerosene and Solar, as cooking fuel, and as a result, the number of cooking fuels per household has significantly decreased. As for the lighting fuel, although the impact of the 2016 earthquake is not observed from the regression results, the use of firewood has increased significantly. These results imply that households are likely to rely relatively more on firewood through seismic shock. Event study analysis shows that the impact of the 2016 earthquake on cooking fuel use is likely to appear not two or three years after the incidence but four or five years after and it is negative. While the impact of the earthquake on cooking fuel use is observed, that on lighting fuel is not still observed except for the positive impact on firewood use.

This paper contributes to the literature as follows. It contributes to the empirical literature investigating the impact of the earthquake on household fuel choice using a quasi-experimental research design. This paper is similar to Paudel (2023), which estimates the impact of seismic shock from the 2015 Nepal earthquake on household fuel choices. However, there is a notable difference in this paper. While Paudel (2023) investigates household "main" fuel choice, this paper examines household fuel choice considering the simultaneous use of other fuels. Taking advantage of this, this paper can assess the energy stacking behavior or the number of fuels per household in response to the 2016 earthquake in Uganda.

The remainder of this paper is organized as follows. Section 2 gives a brief explanation of the 2016 earthquake in Uganda. Section 3 presents the data description and discussion about the definition of the variables. Section 4 describes the empirical strategy and Section 5 reports the empirical analysis. Section 6 concludes with a summary of the main results and policy implications.

2. Background

On 10th September 2016 at 12:27:33.410 UTC, M 5.9 earthquake occurred in Uganda on its depth 40km (USGS[4]). According to United States Geological Survey (USGS), the epicenter of the earthquake was located in Kagera region in Tanzania near the west shore of Lake Victoria (Figure 1). USGS also gives information about the earthquake as follows[5]:

" The September 10, 2016 M 5.9 earthquake near the west shore of Lake Victoria in northern Tanzania occurred as the result of shallow oblique faulting within the lithosphere of the Nubia (Africa) plate. The focal mechanism solution for the earthquake indicates rupture occurred on a moderately dipping fault striking either northeast-southwest (right-lateral slip) or east-west (left-lateral slip).

The location of the September 10, 2016 earthquake broadly places it in the East African Rift System, a 3,000-km-long Cenozoic age continental rift extending from the Afar triple junction (between the horn of Africa and the Middle East), to western Mozambique. In this context, today's earthquake is some 200 km or more to the east of the West Branch of the Rift System, which runs along the border between the Democratic Republic of the Congo and both Uganda (in the north) and Tanzania (to the south). The East Branch of the Rift System runs north-to-south through Kenya and central Tanzania, several hundred kilometers to the east of the September 10 earthquake. The Victoria microplate lies between these two branches of the rift, and helps to accommodate the dominantly divergent (extensional) tectonics of the Rift System, where rift segments are connected by dominantly strike-slip transform faults. The September 10, 2016 earthquake is consistent with this mixed divergent and strike slip setting, and occurred somewhat centrally within that microplate, in an area with little to no recorded earthquakes over the past century."

In the most affected district in Uganda, Rakai district, it is reported that four people died, 20 people were admitted to the hospital with injuries, a total of 590 people were affected, and buildings were seriously damaged, (Balikuddembe and Sinclair 2018). In Balikuddembe and Sinclair (2018), a vivid description of the situation at that time is provided:

---

[4] "M 5.9 - 27 km ENE of Nsunga, Tanzania", United States Geological Survey. https://earthquake.usgs.gov/earthquakes/eventpage/us10006nkx/region-info (accessed 2nd December 2024)

[5] " M 5.9 - 27 km ENE of Nsunga, Tanzania", United States Geological Survey. https://earthquake.usgs.gov/earthquakes/eventpage/us10006nkx/executive (accessed 2nd December 2024)

"This earthquake happened in a weekend and in the afternoon when many people were in their homes, or visiting shopping malls and places used for leisure and entertainment. Others were in offices and at workplaces. The quake was experienced as a strong vibration that rattled the buildings people were occupying. Some people were frightened to see furniture, doors and windows violently shaking and rumbling, cabinets opening, glass panes warping and weak hanging items falling from the walls. Others mistook it for a bomb blast. As a result, many panic-stricken people ran and scampered to exit buildings for their safety."

Although there have been no clear estimates of the real monetary value of the losses and damages in Uganda, in the neighboring country, Tanzania, the economic damage is estimated at $458 million (Balikuddembe and Sinclair 2018).

3. Data

This paper uses a nationally representative panel of household surveys carried out in Uganda (The Uganda National Panel Survey (UNPS)) over four Waves: 2013/14 (Wave 5), 2015/16 (Wave 6), 2018/19 (Wave 7), and 2019/20 (Wave 8). This panel data includes 3,119 households in Wave 5, 3,305 households in Wave 6, 3,176 households in Wave and 3,098 households in Wave 8, respectively. UNPS provides multi-topic household information, such as sex, age and education status of household members, energy use and housing status.

3.3. Definition of the variables

3.3.1. Dependent variables

There are 18 dependent variables in this paper, namely, seven dummy variables as cooking fuel use (firewood, crop residue, kerosene, LPG, charcoal, solar, electricity), seven dummy variables as lighting fuels use (the same as cooking fuels), the number of cooking and lighting fuels a household uses respectively, grid electricity dummy variable, and solar panel ownership dummy variable. Cooking and lighting fuel use dummy variables are defined to take the value of 1 when a household uses a fuel. For example, when a household uses firewood and LPG as cooking fuels and kerosene as a cooking fuel, cooking fuel use dummy variables in firewood and LPG take the value of 1 and the others take the value of 0, and lighting fuel use dummy variable in kerosene takes the value of 1 and the others take the value of 0. The number of cooking and lighting fuels represent a household stacking behavior. For example, in the same household as above, the number of cooking fuels is two and the number of lighting fuels is 1. The grid electricity dummy variable and solar panel ownership dummy variable are defined in that the former takes the value of 1 when a household has access to grid electricity, and the latter takes the value of 1 when a household owns solar panels and electric inverters individually or jointly with non-household members.

3.3.2 Independent variable

To estimate the impact of the 2016 earthquake on the energy transition in Uganda, this paper defines a dummy variable as an independent variable, $Treatment_i$, which takes the value of 1 when a household live in the district with MMI Scale 3.5 (rounded up IV) or more at both Wave 6 and 7 of UNPS. Since MMI scale is based on observed effects, MMI refers to the effects actually experienced at that place[6]. This is why MMI is the best index to represent the impact of the earthquake. At MMI 4[7], seismic impact on the building environment appears for the first time: walls creak and windows rattle. According to the United States Geological Survey (USGS), structural engineers usually care about VIII or above. Thus, MMI IV might not be so severe. However, in developing countries and an area where strong earthquake rarely happens, it is expected that people and buildings are more vulnerable than in other areas like the circum-Pacific orogenic zone or Alpine-Himalayan orogenic belt. Hence, this paper uses MMI 4 as a threshold of treatment status.

This paper uses The ShakeMap Atlas reported by USGS[8] as the seismic information. Since the MMI is not reported at the district level, this paper defines the earthquake-affected district where the district headquarters office is located inside the MMI IV area. Then, 20 districts and the capital city, Kampala, were assigned to treatment districts, and 115 districts were assigned to control districts (See Figure 1).

---

[6] " The Modified Mercalli Intensity (MMI) Scale assigns intensities as ... ", United States Geological Survey.
https://www.usgs.gov/media/images/modified-mercalli-intensity-mmi-scale-assigns-intensities (accessed 30th November 2024)

[7] The other influence is explained as follows:
People's reaction: Felt by many; sensation like heavy body striking building.
Furnishings: Dishes rattle.

[8] " M 5.9 - 27 km ENE of Nsunga, Tanzania", United States Geological Survey.
https://earthquake.usgs.gov/earthquakes/eventpage/us10006nkx/shakemap/intensity (accessed 30th November 2024)

This paper also defines dummy variables, $Post_t$, which takes the value of 1 for both Waves 7 and 8, and $wave7_t$ and $wave8_t$ for Waves 7 and 8, respectively. This paper focuses on the coefficients of the interaction term of $Treatment_i$ and these three variables.

3.3.3. Control variables

Control variables are at household level. It includes age, gender, marital status and education of household head, household size, whether a household live in urban area or not, the number of rooms, and Housing ownership.

3.4 Descriptive statistics

Table 1 summarizes the descriptive statistics of dependent variables comparing before and after the 2016 earthquake and the control and treatment groups.

At first, this paper focuses on the variables before the earthquake. Even though there is a difference between the two groups, firewood (Control: 83% at Wave5 and 84% at Wave6, Treatment: 63% at Wave5 and 59% at Wave6) and charcoal (Control: 23% at Wave5 and 22% at Wave6, Treatment: 44% at Wave5 and 49% at Wave6) are main cooking fuels, and kerosene (Control: 69% at Wave5 and 57% at Wave6, Treatment: 63% at Wave5 and 55% at Wave6) is main lighting fuels. As for the cooking fuel, crop residue (Control: 12% at Wave5 and 20% at Wave6, Treatment: 3% at Wave5 and 7% at Wave6) is also common fuel in the control group and kerosene (Control: 3% at Wave5 and 2% at Wave6, Treatment: 10% at Wave5 and 10% at Wave6) is also common fuel in the treatment group. LPG (Control: 0.5% at Wave5 and 0.4% at Wave6, Treatment: 2% at Wave5 and 3% at Wave6), solar (Control: 0.08% at Wave5 and 0.08% at Wave6, Treatment: 0% at Wave5 and 0.2% at Wave6), and electricity (Control: 0.08% at Wave5 and 0.08% at Wave6, Treatment: 0% at Wave5 and 0.2% at Wave6) are rarely used in both groups. As for the lighting fuel, solar is used in both groups and the ratio of usage increased from Wave5 to Wave6 (Control: 5% at Wave5 and 12% at Wave6, Treatment: 7% at Wave5 and 12% at Wave6). Electricity (Control: 9% at Wave5 and 9% at Wave6, Treatment: 30% at Wave5 and 34% at Wave6) is a common lighting fuel in the treatment group, probably because of higher access to grid electricity (Control: 10% at Wave5 and 10% at Wave6, Treatment: 33% at Wave5 and 37% at Wave6). Some households in the control group use Firewood (Control: 4% at Wave5 and 4% at Wave6, Treatment: 0.2% at Wave5 and 0% at Wave6) as a lighting fuel. Crop residue (Control: 1% at Wave5 and 1% at Wave6, Treatment: 0.2% at Wave5 and 0% at Wave6) and charcoal (Control: 0.1% at Wave5 and 0.1% at Wave6, Treatment: 0.4% at Wave5 and 0% at Wave6) are rarely used in both groups. LPG is never used in both groups over four waves. As for the energy stacking behavior, the number of cooking fuels (Control: 1.22 at Wave5 and 1.29 at Wave6, Treatment: 1.26 at Wave5 and 1.31 at Wave6) is more than one for both groups, but the number of lighting fuels (Control: 0.87 at Wave5 and 0.83 at Wave6, Treatment: 1.01 at Wave5 and 1.00 at Wave6) is approximately one or less than one.

To be focused on the change of the variables between before and after the earthquake, as for the cooking fuels, there is almost no change except for kerosene (Control: 2% at Wave7 and 1.5% at Wave8, Treatment: 6% at Wave7 and 4 at Wave8) in the treatment group. In the lighting fuels, although most of the fuels do not change over the periods, there are notable changes in kerosene (Control: 24% at Wave7 and 20% at Wave8, Treatment: 22% at Wave7 and 15% at Wave8) and solar (Control: 36% at Wave7 and 43% at Wave8, Treatment: 31% at Wave7 and 36 at Wave8). The increase in solar as lighting fuel use can probably be explained by the increase in solar panel ownership (Control: 36% at Wave7 and 43% at Wave8, Treatment: 31% at Wave7 and 37% at Wave8). As for the stacking behavior, the number of the cooking fuels increase in the control group but decrease in the treatment group (Control: 1.32 at Wave7 and 1.34 at Wave8, Treatment: 1.27 at Wave7 and 1.20 at Wave8). lighting fuels in both groups (Control: 0.85 to 0.75, Treatment: 1.00 to 0.89). The number of lighting fuels decrease in both groups (Control: 0.73 at Wave7 and 0.77 at Wave8, Treatment: 0.86 at Wave7 and 0.91 at Wave8).

Table 2 summarizes the descriptive statistics of control variables. Age and female household head ratio are not so much different. The education status of the household head is higher in the treatment group for all categories of education. As for the Household head's marital status, the ratio of household head who is married monogamously and widow or widower are not so much different, but the ratio of household head who is married polygamously and divorced or lives separated from other household members like spouse differ to some extent.

4. Empirical Framework

To assess the impact of the 2016 earthquake in Uganda on household energy transition, this paper uses the Difference-in-Differences (DID) model for a regression estimation because the earthquake is exogenous. This paper estimates the following equation:

$$Y_{it} = \beta_1 Post_t * Treatment_i + \theta X_{it} + f_i + \eta_t + \varepsilon_{it} \quad \cdot\cdot\cdot (1)$$

Where i and t represent the household and waves from Wave5 to Wave8, respectively. Y_{it} is dependent variables as explained Section 3. $Treatment_i$ is a dummy variable taking a value of 1 if a household lives in the affected area as explained Section 3. $Post_t$ is also a dummy variable that takes the value of 1 for both Wave 7 and Wave 8. The X_{it} is a vector of household-level control variables. f_i and η_t are household fixed effect and Wave fixed effect. ε_{it} is the error term. β_1 is the coefficient of interest and captures the causal effect of the earthquake on fuel choice and β_1=0 is the null hypothesis. Since the dataset is panel data, this paper clusters the standard errors to the household level in the regression.

To estimate the impact of seismic shock on cooking fuel choice and lighting fuel choice using equation (1), there are two sets of seven equations. However, one concern comes up here: a choice of fuel may not be independent of a choice of other fuel. For example, when a household chooses firewood as a cooking fuel, the possibility of choosing other fuels may decrease. In this situation, even if the error term of an equation for a fuel is unbiased, it will be correlated to the error term of an equation of the other fuels. Hence, this paper considers the correlation of the error term among equations for cooking fuel choice and lighting fuel choice and estimates Seemingly Unrelated Regression (SUR) with reporting correlation coefficient of the residuals of the regressions for cooking fuels, lighting fuels, and also electricity grid and solar panel ownership[9].

In DID methods, the Parallel Trend assumption needs to be satisfied: If an exogenous shock did not happen, the time trend is to be the same between the treatment and control groups. To confirm the Parallel Trend assumption and to assess the two- or three-year and three- or four-year impact of the seismic shock, this paper also estimates the following equation for Event Study:

$$\begin{gathered} Y_{it} = \beta_1 wave5_t * Treatment_i + \beta_2 wave7_t * Treatment_i + \beta_3 wave8_t * Treatment_i \\ + \theta X_{it} + f_i + \eta_t + \varepsilon_{it} \quad \cdot\cdot\cdot (2) \end{gathered}$$

---

[9] The author of this paper uses R to estimate the regressions, but no R package covers SUR with fixed effect and clustered standard error. However, since the regressors are completely the same among equations, the coefficient estimated through SUR are equivalent to the coefficient estimated separately through OLS as explained by (Hansen 2022). Therefore, the author regress separately using OLS with fixed effects and clustered standard error, obtain the residual, and calculate the correlation coefficient.

$wave5_t$, $wave7_t$, and $wave8_t$ are dummy variables which take value of 1 for Wave 5, Wave 8, and Wave 8 respectively. β_1, β_2, and β_3 are the coefficients of interest. β_1 captures the pre-trend before the 2016 earthquake. If β_1=0 is confirmed, the parallel trend assumption should be met, and the treatment effect should be unbiased. β_2 represents the causal effect of the earthquake on household fuel choice two- or three years after the earthquake. β_3 represents the causal effect three- or four- after. β_1=β_2= 0 is the null hypothesis. The other definitions of the variables are the same as equation (1).

5. Results

5.1 Difference-in-differences design

Table 3 presents DID estimates of the overall impact of the 2016 earthquake on household cooking fuel choice with equation (1). The first column of each dependent variables includes household characteristics as control variables and Wave fixed effect, the second column also includes time-invariant household fixed effect in addition to that, and the third column, the most preferable specification, includes not only control variables and fixed effects but also interaction term of urban dummy and Wave dummy to capture the urban time trend represented to development in urban area.

The coefficient of the interaction term -0.030 in Column (9) and -0.012 in Column (18) implies that there is a significant decrease in the use of kerosene (3 percent point at 5% significant level) and solar (1.2 percent point at 0.1% significant level) as a source of cooking fuel among households of treated districts in response to seismic shock from the 2016 earthquake. While the effect of the 2016 earthquake on the use of kerosene and solar is negative and statistically significant at the 95% level or above, the effect on firewood, crop residue, LPG, charcoal, and electricity is negative and statistically insignificant. Column (24) shows DID estimates of the impact on the number of cooking fuels of a household. The coefficient of -0.098 (at 1% significant level) implies a significant 10.3% decrease[10] in the number of cooking fuels per household. Table 4 shows the correlation coefficients of the error term among seven equations for cooking fuels. The fact that Most of the absolute values of correlation coefficients are under 0.2 except for firewood and charcoal (-0.22) implies that most of the choice of cooking fuel is almost independent, and there is, but a very weak, a negative correlation between firewood and charcoal. In other words, firewood and charcoal as

[10] Slope coefficient of -0.119 translates to -(exp(0.098)-1) = -0.1029628

cooking fuel tend to substitute, but very weakly.

Table 5 presents DID estimates of the overall impact of the 2016 earthquake on household lighting fuel choice with equation (1)[11]. Empirical methods are the same as cooking fuels. The coefficient of the interaction term 0.012 in Column (3) implies that there is a significant increase in the use of firewood (1.2 percent point at 1% significant level). While the effect of the 2016 earthquake on the use of firewood is statistically significant, the effect on the other fuels is negative and insignificant, except for electricity, with a positive and insignificant coefficient. Comparing the coefficients in Column (14) with significant and negative effects and (15) with insignificant and negative effects, it is implied that the use of solar as lighting fuel may be correlated to the urban time trend like development in urban cities. Column (21) shows DID estimates of the overall impact on the number of lighting fuels in a household. The impact on the energy stacking behavior for lighting fuel is negative and statistically insignificant. Table 6 shows the correlation coefficients of the error term among six equations for lighting fuels. While most of the absolute values of correlation coefficients are under 0.2, kerosene and solar have weak negative correlation (-0.302). In other words, kerosene and solar as lighting fuel tend to weakly substitute.

Table 7 shows DID estimates of the impact of the 2016 earthquake on household access to grid electricity and solar panel ownership. Column (3) implies a positive but insignificant impact on access to grid and Column (6) implies a negative but insignificant impact on solar ownership for both periods. Comparison between Column (2) and (3), and Column (5) and (6) indicates that urban Wave trend may be correlated to the access to grid electricity and solar panel ownership. Table 8 reports that the correlation of electricity use and access to grid (0.7646) and that of solar use and solar panel ownership (0.8057) are positive and very strong.

These results indicate that the seismic shock from the 2016 earthquake in Uganda decreases the use of most of the cooking fuels and as a result, the number of cooking fuels used in a household decrease. According to Heltberg (2005), the "inverse U" curve is found in the number of fuels used for cooking as household expenditure increases (See Figure 2). Based on his findings and energy ladder theory, the results of this paper imply that the seismic shock from the 2016 earthquake may affect some economic status and as a result, household climb the energy ladder up to modern fuel like LPG and electricity, or down to primitive fuel like firewood and crop residue while abandoning transition fuel like kerosene or charcoal for cooking fuel. As Table 1 shows, since the use of LPG and electricity as cooking fuel is rare and the use of firewood is more common in Uganda, households are likely to climb down the energy ladder and rely relatively more on firewood.

---

[11] Since there is no variance in the use of LPG as a lighting fuel between groups and over time, the regression for LPG as a lighting fuel is excluded.

5.2. Event study

5.2.1. Parallel Trend assumption

Table 9 shows the results of event study regression on household cooking fuel using equation (2). All regressions include household characteristic as control variables, Wave fixed effect, household fixed effect, and urban Wave trend. The first row of the table, Treatment: Wave5, reports the coefficient of interaction term of Treatment and Wave5 dummy variables. Since all the coefficients is statistically insignificant before the earthquake, this imply that there does not exist any pre-trend in household cooking fuel use before the earthquake.

Table 10 shows the results of event study regression on household lighting fuel using equation (2). With insignificant coefficients for all dependent variables in the first row, this indicate that there is no pre-trend in household lighting fuel use before the earthquake as well as cooking fuel.

5.2.2. DID results by Wave

The second row and the third row in Table 9 shows respectively DID estimates of the two- or three- years impact and three- or four- years impact of the 2016 earthquake on household cooking fuel choice with equation (2). Column (6) implies that the two- or three- years significant impact of the earthquake is observed only in solar, and it is negative (1.1 precent point at 5% significant level). Column (2), (3), (5) and (6) implies that the shock from the 2016 earthquake decrease the use of crop residue (4.9 percent point at 5% significant level), kerosene (3.3 percent point at 5% significant level), charcoal (4.9 percent point at 5% significant level), and solar (4.9 percent point at 5% significant level). Column (8) shows that the impact of the earthquake on the number of cooking fuel appears only in Wave 8.

The second row and the third row in Table 10 shows DID estimates of the two- or three- years impact and three- or four- years impact of the 2016 earthquake on household lighting fuel choice respectively with equation (2). Column (1) indicates that the impact of the earthquake on firewood as lighting fuel is positive and significant (1 percent point for Wave 7 and 1.1 percent point for Wave 8 at 5% significant level respectively).

Table 11 shows the impact of the earthquake on access to grid and solar panel ownership by Wave. Pre-trend does not exist but also the impact is not observed after the earthquake.

5.3. Robustness check

Although this paper defines a threshold which divides the sample into control and treatment group discretely, in fact, the border of the earthquake affected area or not is continuous and indistinct. Therefore, the impact of the 2016 earthquake may be observed around the affected district defined in this paper. In this sub section, this paper assesses the impact of the earthquake on fuel choice by defining household lives Northern and Eastern region in Uganda as control group. Since Northern and Eastern region are geographically remote from epicenter, it can be said that those who live there are not affected by the 2016 earthquake at all.

Table 12 shows DID estimates of the impact of the 2016 earthquake on cooking fuel choice by group, with the control group restricted to Northern and Eastern region. Except for crop residue, pre-trend does not exist. The regression results imply that the impact on the use of crop residue in the long run and on the use of kerosene and solar for both periods are still negative and statistically significant, but the absolute value is lager in this subgroup estimation than all sample estimation and as for crop residue parallel trend assumption will be violated. Column (5) implies the impact on the use of charcoal is still negative but turns to be statistically significant at 5% significant level in Wave 8. Column (8) implies that the impact is still negative but seems larger in the subsample estimation. These findings imply that cooking fuel choice in control group in the Central and Western region may also be affected by the 2016 earthquake.

Table 13 shows DID estimates of the impact of the 2016 earthquake on lighting fuel choice by Wave with subsample estimation. Column (1) and (2) implies the impact on firewood use are still robust in Wave 7. Column (3) shows that the impact on the use of kerosene turns larger and statistically significant in both Wave 7 and 8. The long run impact on electricity use is also significant as shown in Column (6). Column (8) shows that the impact on the number of lighting fuel is still negative and insignificant.

These findings imply that findings on change in fuel choice aftermath of the 2016 earthquake are robust but most of fuel choice of the control group in Western and Central region may also be affected by the 2016 earthquake. Moreover, it can be said that the impact on the use of solar and electricity as lighting fuel appears only in the treatment group.

6. Conclusion and policy implication

This paper examines the impact of the 2016 earthquake on household fuel choice and energy stacking behavior in a developing country setting. Specifically, as the empirical strategy, this paper uses the regional variation in MMI of the 2016 earthquake to estimate changes in fuel choices at the household level. Findings from a difference-in-differences research design reveals that households exposed to moderate seismic shock are likely to reduce the number of cooking fuels over all after the 2016 earthquake and increase relative reliance on firewood as cooking fuel.

As for the decrease in the number of cooking fuel, Heltberg (2005) finds that in rural areas, in urban areas, there is "inverse U" curve with the number of fuels initially increasing as welfare grows (See Figure 2). According to the energy ladder theory, as many articles related to energy switching indicates (Choumert-Nkolo et.al., 2018), Heltberg (2004, 2005)), households switch fuels from primitive fuels, such as firewood and crop residue, through transition fuels, such as charcoal and kerosene, to advanced fuels, such as LPG and electricity. Moreover, price of fuels is one of the important factors which determines household fuel choice (Alem et.al., 2016). Paudel (2023) says that unit prices of firewood decreased significantly in response to the 2015 earthquake in Nepal, and that causes households in earthquake-affected districts to rely more on firewood as a source of cooking fuel. Therefore, the findings in this paper that the usage of most of the fuels decrease and that of firewood, LPG, and electricity do not change significantly thorough seismic shock, and the fact that LPG and electricity are seldom used in Uganda, imply that households reduce the number of cooking fuels because of the economic loss or the price shock in some kind of fuels, and increase relative reliance on firewood as a cooking fuel. This supports the existence of the left side of "inverse U" curve of Heltberg (2005)'s finding.

These findings suggest some policy implication. Policy makers in Uganda, as refer in NDP III, aim to reduce the use of firewood and increase the access to and use of electricity in household fuel choice because electricity, most of which is generated from renewable energy like hydropower, is clean and efficient energy in Uganda. This paper does not imply that the seismic shock has an impact on the reduction of use of electricity but imply that it has an impact on the increase in the relative reliance on firewood. Hence, when policy makers aim for energy transition from primitive biomass energy to modern clean energy, they should keep in mind that natural disaster like earthquake can hinder the process of household energy transition or regress it and should take appropriate actions against it. Firstly, policy makers should subsidize the affected households to recover their undermined economic status which this paper hypothesizes as one of the main causes of the negative effect of earthquake on household fuel choice. Secondly, destruction of infrastructures, reduction in quantity of modern energy supply, and rise of modern energy price in natural disaster crisis can also be the causes of the negative effect on energy choice, policy makers should build a resilient energy supply system to mitigate the impact of natural disaster on fuel choice. Thirdly, as natural disaster can be an opportunity to change behavior in energy use (Fujimi and Chang 2014), policy makers can promote energy transition in recovery from natural disaster. In order to achieve energy transition, it is important for policy makers to prepare for natural disaster and help household to make better fuel choice after natural disaster.

7. References

Alem, Yonas, et al. "Modeling Household Cooking Fuel Choice: A Panel Multinomial Logit Approach." *Energy Economics* 59 (2016): 129–137.

Balikuddembe, Joseph Kimuli, and Paul Sinclair. "Uganda at Glance of 5.7 Magnitude Earthquake: Lessons for Earthquake Risk Reduction." *PLoS Currents* 10 (2018).

Bui, A. T., Mardi Dungey, C. V. Nguyen, and T. P. Pham. "The Impact of Natural Disasters on Household Income, Expenditure, Poverty, and Inequality: Evidence from Vietnam." *Applied Economics* 46, no. 15 (2014): 1751–66.

Choumert-Nkolo, Johanna, Pascale Combes Motel, and Leonard Le Roux. "Stacking up the Ladder: A Panel Data Analysis of Tanzanian Household Fuel choices." *World Development* 115 (2019): 222–235.

Duflo, Esther, Michael Greenstone, and Rema Hanna. "Cooking Stoves, Indoor Air Pollution, and Respiratory Health in Rural Orissa." *Economic and Political Weekly* 43, no. 32 (2008): 71–76.

Fujimi, Toshio, and Stephanie E. Chang. "Adaptation to electricity crisis: Businesses in the 2011 Great East Japan triple disaster." *Energy Policy* 68 (2014): 447-457.

Geist, H. J., and E. F. Lambin. "Proximate Causes and Underlying Driving Forces of Tropical Deforestation." *BioScience* 52, no. 2 (2002): 143–51.

Ghobarah, Ahmed, Murat Saatcioglu, and Ioan Nistor. "The Impact of the 26 December 2004 Earthquake and Tsunami on Structures and Infrastructure." *Engineering Structures* 28, no. 2

(2006): 312–26.

Hansen, Bruce E. "*Econometrics*." University of Wisconsin, Department of Economics, March 11, 2021.

Heltberg, Rasmus. "Factors Determining Household Fuel Choice in Guatemala." *Environment and Development Economics* 10, no. 3 (2005): 337–361.

Heltberg, Rasmus. "Fuel Switching: Evidence from Eight Developing Countries." *Energy Economics* 26, no. 5 (2004): 869–887.

IEA, IRENA, UNSD, World Bank, WHO. 2024. "Tracking SDG 7: The Energy Progress Report." World Bank, Washington DC. © World Bank. License: Creative Commons Attribution—NonCommercial 3.0 IGO (CC BY-NC 3.0 IGO).

Masera, Omar R., Barbara D. Saatkamp, and Daniel M. Kammen. "From Linear Fuel Switching to Multiple Cooking Strategies: A Critique and Alternative to the Energy Ladder Model." *World Development* 28, no. 12 (2000): 2083–2103.

Mottaleb, K. A., Samarendu Mohanty, H. T. K. Hoang, and Roderick M. Rejesus. "The Effects of Natural Disasters on Farm Household Income and Expenditures: A Study on Rice Farmers in Bangladesh." *Agricultural Systems* 121, no. C (2013): 43–52.

Parikh, J., K. Balakrishnan, V. Laxmi, and H. Biswas. "Exposure from Cooking with Biofuels: Pollution Monitoring and Analysis for Rural Tamil Nadu, India." *Energy* 26, no. 10 (2001): 949–962.

Paudel, Jayash. "Shaking Things up: Do Seismic Shocks Affect Fuel choices?" *Energy Policy* 172 (2023): 113297.

Rao, M. N., and B. S. Reddy. "Variations in Energy Use by Indian Households: An Analysis of Micro-Level Data." *Energy* 32, no. 2 (2007): 143–153.

Schlag, Nicole, and Fanny Zuzarte. *Market Barriers to Clean Cooking Fuels in Sub-Saharan Africa: A Review of Literature.* Stockholm Environment Institute, 2008.

Uganda National Planning Authority, "Third National Development Plan (NDPIII) 2020/21-2024/25", Republic of Uganda, 2020.

Van der Kroon Bianca, Roy Brouwer, and Pieter Jh Van Beukering. "The Energy Ladder: Theoretical Myth or Empirical Truth? Results from a Meta-Analysis." *Renewable and Sustainable Energy Reviews* 20 (2013): 504–513.

Data sets

Uganda Bureau of Statistics. *National Panel Survey 2019–2020* [Data set]. World Bank, Development Data Group, 2021. https://doi.org/10.48529/NQZX-F196. Dataset downloaded from https://microdata.worldbank.org/index.php/catalog/3902/get-microdata on October 21, 2024.

Uganda Bureau of Statistics. *National Panel Survey 2018–2019* [Data set]. World Bank, Development Data Group, 2021. https://doi.org/10.48529/NQZX-F196. Dataset downloaded from https://microdata.worldbank.org/index.php/catalog/3795/get-microdata on October 21, 2024.

Uganda Bureau of Statistics. *National Panel Survey 2015–2016* [Data set]. World Bank, Development Data Group, 2019. https://doi.org/10.48529/HM2Z-2K12. Dataset downloaded from https://microdata.worldbank.org/index.php/catalog/3460/get-microdata on October 21, 2024.

Uganda Bureau of Statistics. *National Panel Survey 2013–2014* [Data set]. World Bank, Development Data Group, 2016. https://doi.org/10.48529/C1C4-H654. Dataset downloaded from https://microdata.worldbank.org/index.php/catalog/2663/get-microdata on October 21, 2024.

8. Figures and Tables

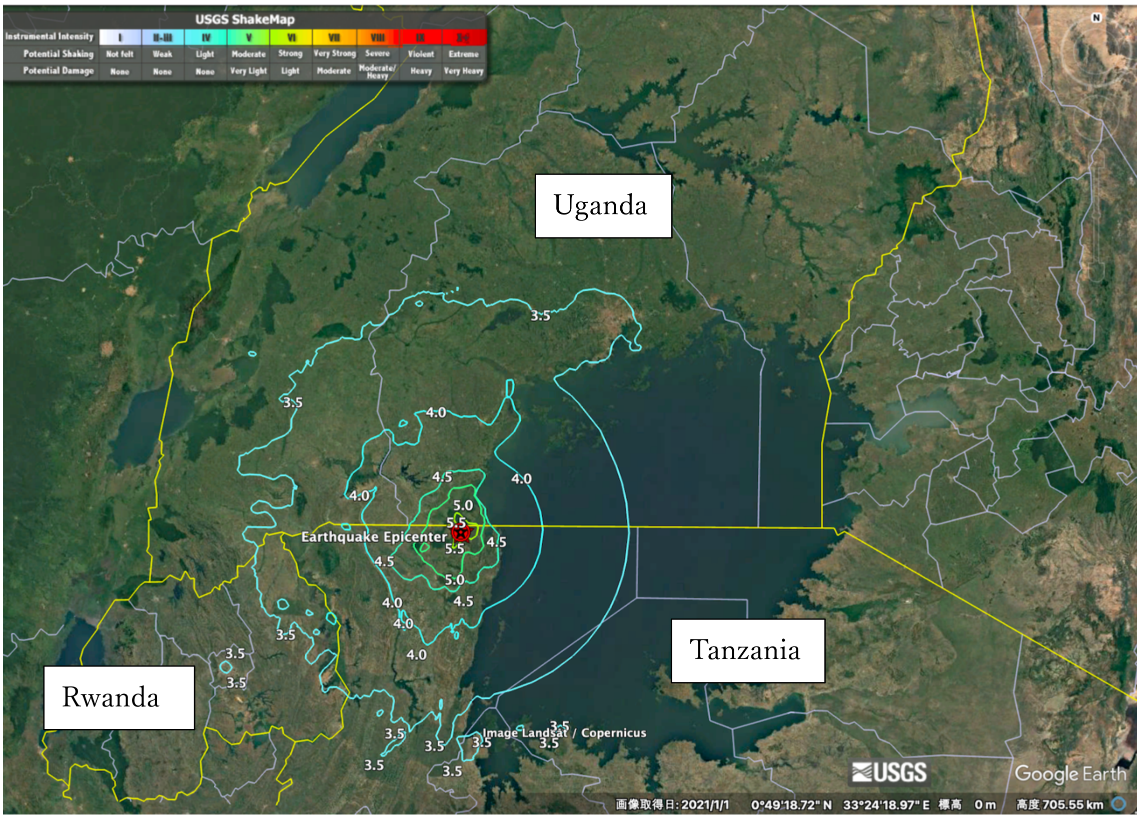

Figure 1: The 2016 earthquake in Uganda exposed area.

Source: Google Earth Pro and USGS[12]

note: The blue and green lines represent contours of MMI of the 2016 earthquake. The outermost contour line represents the MMI 3.5 boundary. This paper defines affected districts as whose headquarter office is located inside MMI 3.5 contours.

[12] https://earthquake.usgs.gov/earthquakes/eventpage/us10006nkx/shakemap/intensity (accessed 2nd December 2024)

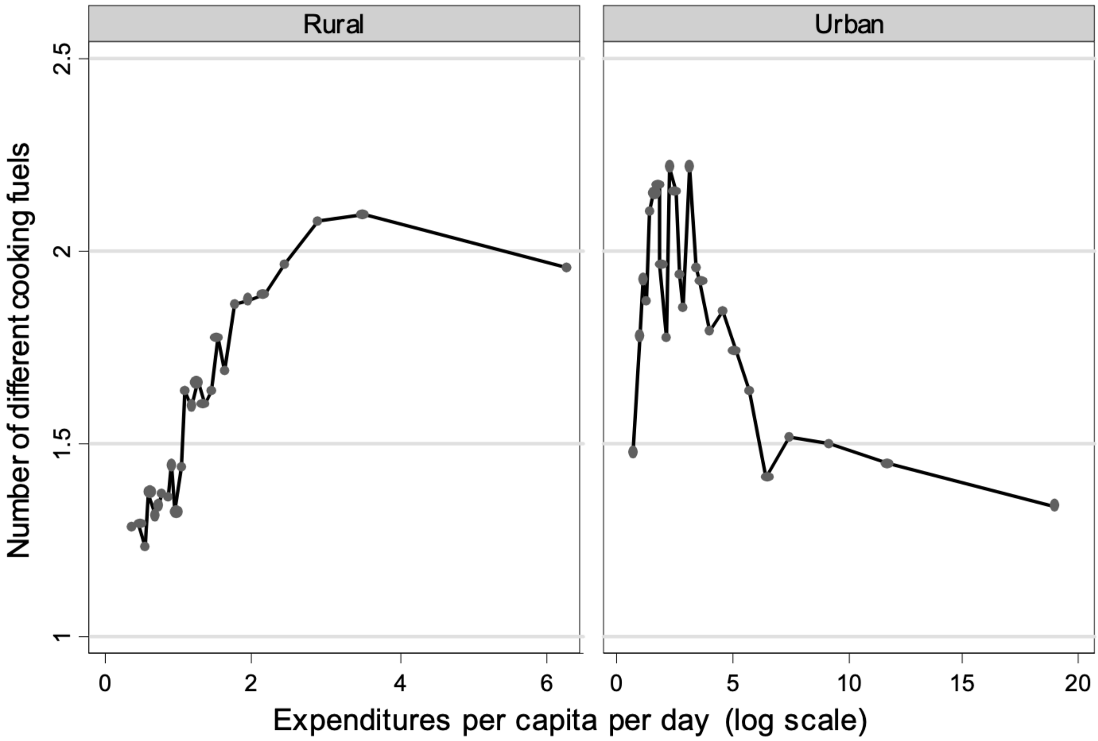

Figure 2: Heltberg (2005)'s "inverse U" curve.
Source: Heltberg (2005), Figure 4: Average number of cooking fuels

note: This figure shows the change in number of cooking fuels as welfare grows per household in Guatemala.

		Before		**After**	
		Wave5 (2013 − 2014)	**Wave6** (2015 − 2016)	**Wave7** (2018 − 2019)	**Wave8** (2019 − 2020)
Cooking fuels					
Firewood(%)	Control	83.10	84.39	85.94	83.87
		(37.48)	(36.30)	(34.77)	(36.79)
	Treatment	63.18	59.28	60.42	59.82
		(48.28)	(49.17)	(48.94)	(49.07)
Crop residue(%)	Control	11.50	19.74	20.59	23.24
		(31.91)	(39.81)	(40.44)	(42.25)
	Treatment	3.36	6.70	9.93	6.32
		(18.05)	(25.03)	(29.94)	(24.35)
Kerosene(%)	Control	3.41	2.14	1.99	1.50
		(18.16)	(14.49)	(13.97)	(12.17)
	Treatment	10.47	10.31	6.03	4.21
		(30.64)	(30.43)	(23.82)	(20.10)
LPG(%)	Control	0.52	0.44	0.40	0.24
		(7.16)	(6.60)	(6.30)	(4.93)
	Treatment	1.87	3.09	1.95	2.11
		(13.56)	(17.33)	(13.85)	(14.37)
Charcoal(%)	Control	23.09	21.84	20.55	22.63
		(42.15)	(41.33)	(40.41)	(41.85)
	Treatment	44.30	49.48	46.09	44.56
		(49.72)	(50.04)	(49.89)	(49.75)
Solar(%)	Control	0.08	0.08	1.55	1.42
		(2.82)	(2.82)	(12.37)	(11.84)
	Treatment	0	0.17	0.33	0
		(0)	(4.15)	(5.70)	(0)
Electricity(%)	Control	0.67	0.32	0.48	0.81
		(8.19)	(5.63)	(6.90)	(8.98)
	Treatment	2.43	2.41	2.28	2.63
		(15.41)	(15.34)	(14.94)	(16.02)
Lighting fuels					
Firewood(%)	Control	3.81	3.81	3.58	3.05
		(19.14)	(19.15)	(18.59)	(17.19)
	Treatment	0.19	0	0	0.18
		(4.32)	(0)	(0)	(4.19)
Crop residue(%)	Control	0.63	0.95	1.27	1.75
		(7.94)	(9.72)	(11.22)	(13.11)
	Treatment	0.19	0	0	0
		(4.32)	(0)	(0)	(0)
Kerosene(%)	Control	68.66	56.87	23.54	19.26
		(46.40)	(49.54)	(42.43)	(39.44)
	Treatment	63.18	54.98	21.99	15.44
		(48.28)	(49.79)	(41.45)	(36.16)
LPG(%)	Control	0	0	0	0
		(0)	(0)	(0)	(0)
	Treatment	0	0	0	0
		(0)	(0)	(0)	(0)
Charcoal(%)	Control	0.08	0.12	0	0.08
		(2.82)	(3.45)	(0)	(2.85)
	Treatment	0.37	0	0	0
		(6.11)	(0)	(0)	(0)
Solar(%)	Control	5.12	11.87	36.32	42.75
		(22.04)	(32.36)	(48.10)	(49.48)
	Treatment	7.29	11.51	31.11	36.49
		(26.02)	(31.94)	(46.33)	(48.18)
Electricity(%)	Control	9.00	9.13	8.32	10.52
		(28.63)	(28.82)	(27.63)	(30.69)
	Treatment	29.53	33.51	33.22	39.12
		(45.66)	(47.24)	(47.14)	(48.85)
Stacking behavior					
Cooking	Control	1.22	1.29	1.32	1.34
		(0.51)	(0.55)	(0.60)	(0.62)
	Treatment	1.26	1.31	1.27	1.20
		(0.57)	(0.57)	(0.57)	(0.54)
Lighting	Control	0.87	0.83	0.73	0.77
		(0.48)	(0.54)	(0.57)	(0.57)
	Treatment	1.01	1.00	0.86	0.91
		(0.48)	(0.48)	(0.43)	(0.38)
Other					
Grid(%)	Control	9.84	9.89	9.56	11.54
		(29.79)	(29.86)	(29.41)	(31.96)
	Treatment	32.71	36.60	39.90	42.28
		(46.96)	(48.21)	(49.01)	(49.44)
Solar panel ownership(%)	Control	5.95	13.39	35.52	43.13
		(23.66)	(34.06)	(47.87)	(49.54)
	Treatment	7.10	12.03	30.56	37.43
		(25.71)	(32.56)	(46.10)	(48.44)
N	Control	2521	2518	2511	2461
	Treatment	535	582	614	570

Note: Mean and standard deviation (in parenthesis) of variables are reported in this table. The number of the observations is listed at the bottom of the table.

Table 1: Summary statistics of dependent variables

		Before		After	
		Wave5 (2013 − 2014)	**Wave6** (2015 − 2016)	**Wave7** (2018 − 2019)	**Wave8** (2019 − 2020)
HH head basic information					
Age	Control	45.33	45.29	47.37	48.01
		(15.98)	(16.14)	(15.99)	(16.13)
	Treatment	45.84	45.38	47.60	48.81
		(14.66)	(14.54)	(14.52)	(14.52)
$Gender(female = 1)(\%)$	Control	31.14	32.41	33.53	34.62
		(46.32)	(46.81)	(47.22)	(47.59)
	Treatment	35.89	35.74	39.25	40.00
		(48.01)	(47.96)	(48.87)	(49.03)
HH head education					
Primary completed(%)	Control	44.74	45.63	43.73	44.25
		(49.73)	(49.82)	(49.61)	(17.19)
	Treatment	56.45	57.04	56.03	55.09
		(49.63)	(49.54)	(49.68)	(49.78)
Secondary completed(%)	Control	15.59	16.08	13.78	14.30
		(36.28)	(36.75)	(34.48)	(13.11)
	Treatment	23.36	26.63	25.24	23.16
		(42.35)	(44.24)	(43.48)	(42.22)
Degree or above(%)	Control	2.06	1.87	1.79	1.79
		(14.22)	(13.54)	(13.27)	(13.25)
	Treatment	5.23	5.50	5.05	3.86
		(22.29)	(22.81)	(21.91)	(19.28)
HH head marital status					
Married monogamously(%)	Control	55.45	55.00	55.95	54.16
		(49.71)	(49.76)	(49.65)	(49.84)
	Treatment	52.15	53.44	51.30	50.00
		(50.00)	(49.92)	(50.02)	(50.04)
Married polygamously(%)	Control	18.64	18.67	17.76	18.04
		(38.95)	(38.97)	(38.23)	(38.46)
	Treatment	12.34	10.14	12.87	13.16
		(32.92)	(30.21)	(33.51)	(33.83)
Divorced/separated(%)	Control	8.21	9.05	8.32	8.66
		(27.46)	(28.70)	(27.63)	(28.12)
	Treatment	13.64	16.67	17.92	17.89
		(34.36)	(37.30)	(38.38)	(38.36)
Widow/Widower(%)	Control	14.20	14.22	16.13	16.62
		(34.91)	(34.93)	(35.23)	(37.23)
	Treatment	15.89	14.78	14.50	15.79
		(36.59)	(35.52)	(0.43)	(36.50)
HH housing status					
Household size	Control	5.60	4.99	5.33	5.22
		(2.98)	(2.88)	(2.79)	(2.76)
	Treatment	5.52	4.66	4.82	4.70
		(3.05)	(2.86)	(2.73)	(2.61)
No. rooms for sleeping	Control	2.22	2.22	2.13	2.16
		(1.22)	(1.17)	(1.08)	(1.09)
	Treatment	2.30	2.18	2.13	2.10
		(1.19)	(1.16)	(1.12)	(1.08)
$Ownership(occupied = 1)(\%)$	Control	83.93	85.50	87.30	86.14
		(36.73)	(35.21)	(33.31)	(34.56)
	Treatment	69.72	68.73	70.36	72.81
		(45.99)	(46.40)	(45.70)	(44.53)
Urban(%)	Control	22.89	20.61	19.55	18.65
		(42.02)	(40.46)	(39.67)	(38.96)
	Treatment	40.56	44.67	49.35	48.07
		(49.15)	(49.76)	(50.04)	(50.01)
N	Control	2521	2518	2511	2461
	Treatment	535	582	614	570

Note: Mean and standard deviation (in parenthesis) of variables are reported in this table. The number of the observations is listed at the bottom of the table.

Table 2: Summary statistics of control variables

	Firewood			Crop residue			Kerosene			LPG		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Treatment:Post	-0.073^{***}	0.003	-0.001	-0.087^{***}	-0.038^{*}	-0.026	0.011	-0.040^{**}	-0.030^{*}	0.008	-0.002	-0.003
	(0.014)	(0.015)	(0.016)	(0.011)	(0.016)	(0.017)	(0.007)	(0.013)	(0.012)	(0.004)	(0.006)	(0.005)
HH characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HH FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Urban wave trend	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes
R^2	0.461	0.812	0.812	0.065	0.538	0.540	0.054	0.520	0.522	0.094	0.725	0.726
Adj. R^2	0.460	0.727	0.727	0.063	0.328	0.330	0.052	0.302	0.304	0.093	0.601	0.601
Num. obs.	12312	12312	12312	12312	12312	12312	12312	12312	12312	12312	12312	12312
RMSE	0.295	0.209	0.209	0.295	0.304	0.304	0.173	0.149	0.149	0.082	0.054	0.054
N Clusters	3827	3827	3827	3827	3827	3827	3827	3827	3827	3827	3827	3827

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

	Charcoal			Solar			Electricity			Num. fuels		
	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
Treatment:Post	0.062^{***}	-0.025	-0.023	-0.012^{***}	-0.014^{***}	-0.012^{***}	0.008	-0.001	-0.001	-0.084^{***}	-0.119^{***}	-0.098^{**}
	(0.015)	(0.018)	(0.019)	(0.002)	(0.003)	(0.003)	(0.005)	(0.003)	(0.007)	(0.021)	(0.030)	(0.030)
HH characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HH FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Urban wave trend	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes
R^2	0.347	0.751	0.751	0.011	0.284	0.284	0.046	0.470	0.470	0.051	0.525	0.527
Adj. R^2	0.346	0.638	0.638	0.010	-0.041	-0.041	0.045	0.229	0.230	0.050	0.309	0.312
Num. obs.	12312	12312	12312	12312	12312	12312	12312	12312	12312	12312	12312	12312
RMSE	0.357	0.266	0.266	0.080	0.082	0.082	0.093	0.084	0.084	0.558	0.476	0.475
N Clusters	3827	3827	3827	3827	3827	3827	3827	3827	3827	3827	3827	3827

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Note: Household characteristics include age, Age, Gender, Marital status and Education of household head, Household size, Urban or not, The number of rooms, and Housing ownership.Standard errors are clustered at the household level.

Table 3: The impact of 2016 earthquake on cooking fuel choice in Uganda.

	Firewood	Crop residue	Kerosen	LPG	Charcoal	Solar	Electricity
Firewood	1.0000						
Crop_residue	0.0640	1.0000					
Kerosene	-0.0135	0.0139	1.0000				
LPG	0.0051	-0.0030	0.0015	1.0000			
Charcoal	-0.2204	-0.0354	0.0074	-0.0299	1.0000		
Solar	0.0095	0.0288	-0.0149	0.0013	0.0074	1.0000	
Electricity	0.0070	-0.0018	0.0137	0.0644	-0.0255	-0.0016	1.0000

Note: This matrix represents the correlation coefficients between the residuals obtained from one regression and the residuals from other regressions.

Table 4: Correlation Matrix for cooking fuels (Residuals)

	Firewood			**Crop residue**			**Kerosene**			**Charcoal**		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Treatment:Post	-0.022^{***}	0.012^{**}	0.012^{**}	-0.011^{***}	-0.006^{*}	-0.005	0.020	0.011	-0.009	0.000	-0.001	-0.000
	(0.003)	(0.004)	(0.004)	(0.002)	(0.003)	(0.003)	(0.015)	(0.025)	(0.026)	(0.001)	(0.002)	(0.002)
HH characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HH FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Urban wave trend	No	No	Yes	No	No	Yes	No	No	Yes	No	No	Yes
R^2	0.029	0.630	0.630	0.013	0.503	0.503	0.212	0.641	0.642	0.002	0.284	0.285
Adj. R^2	0.028	0.462	0.462	0.012	0.278	0.277	0.211	0.478	0.479	0.001	-0.041	-0.040
Num. obs.	12312	12312	12312	12312	12312	12312	12312	12312	12312	12312	12312	12312
RMSE	0.166	0.123	0.123	0.096	0.082	0.082	0.438	0.356	0.356	0.028	0.029	0.029
N Clusters	3827	3827	3827	3827	3827	3827	3827	3827	3827	3827	3827	3827

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

	Solar			**Electricity**			**Num. fuels**		
	(16)	(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)
Treatment:Post	-0.017	-0.081^{***}	-0.039	0.140^{***}	0.026	0.014	0.111^{***}	-0.040	-0.028
	(0.019)	(0.023)	(0.024)	(0.014)	(0.017)	(0.017)	(0.016)	(0.027)	(0.027)
HH characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HH FE	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Urban wave trend	No	No	Yes	No	No	Yes	No	No	Yes
R^2	0.176	0.600	0.605	0.338	0.785	0.786	0.044	0.524	0.524
Adj. R^2	0.175	0.419	0.426	0.337	0.687	0.689	0.042	0.307	0.307
Num. obs.	12312	12312	12312	12312	12312	12312	12312	12312	12312
RMSE	0.385	0.323	0.321	0.281	0.193	0.193	0.518	0.441	0.441
N Clusters	3827	3827	3827	3827	3827	3827	3827	3827	3827

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Note: Household characteristics include age, Age, Gender, Marital status and Education of household head, Household size, Urban or not, The number of rooms, and Housing ownership.Standard errors are clustered at the household level.

Table 5: The impact of 2016 earthquake on lighting fuel choice in Uganda.

	Firewood	Crop residue	Kerosen	Charcoal	Solar	Electricity
Firewood	1.0000					
Crop_residue	0.1654	1.0000				
Kerosene	-0.0327	0.0228	1.0000			
Charcoal	-0.0007	-0.0001	-0.0052	1.0000		
Solar	0.0070	-0.0189	-0.3024	0.0007	1.0000	
Electricity	0.0065	0.0010	-0.0993	-0.0040	-0.1149	1.0000

Note: This matrix represents the correlation coefficients between the residuals obtained from one regression and the residuals from other regressions.

Table 6: Correlation Matrix for lighting fuels (Residuals)

	Grid			**Solar panel**		
	(1)	(2)	(3)	(4)	(5)	(6)
Treatment:Post	0.163^{***}	0.041^{**}	0.023	-0.010	-0.066^{**}	-0.029
	(0.014)	(0.016)	(0.016)	(0.019)	(0.023)	(0.024)
HH characteristics	Yes	Yes	Yes	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes	Yes	Yes	Yes
HH FE	No	Yes	Yes	No	Yes	Yes
Urban wave trend	No	No	Yes	No	No	Yes
R^2	0.391	0.835	0.837	0.175	0.610	0.613
Adj. R^2	0.390	0.760	0.763	0.174	0.432	0.438
Num. obs.	12312	12312	12312	12296	12296	12296
RMSE	0.282	0.177	0.176	0.388	0.322	0.320
N Clusters	3827	3827	3827	3826	3826	3826

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$
Note: Household characteristics include age, Age, Gender, Marital status and Education of household head, Household size, Urban or not, The number of rooms, and Housing ownership. Standard errors are clustered at the household level.

Table 7: The impact of 2016 earthquake on household grid status and solar panel ownership in Uganda

	Electricity lighting	Solar lighting	Grid	Solar panel
Electricity lighting	1.0000			
Solar lighting	-0.1131	1.0000		
Grid	0.7646	-0.1248	1.0000	
Solar panel	-0.0850	0.8057	-0.0953	1.0000

Note: This matrix represents the correlation coefficients between the residuals obtained from one regression and the residuals from other regressions.

Table 8: Correlation Matrix of the use of Electricity and solar as lighting fuel, Grid and Solar Panel

	Firewood (1)	Crop residue (2)	Kerosen (3)	LPG (4)	Charcoal (5)	Solar (6)	Electricity (7)	Num. fuels (8)
Treatment:Wave5	0.004	0.024	−0.004	−0.008	−0.035	−0.004	−0.004	−0.025
	(0.016)	(0.016)	(0.016)	(0.005)	(0.022)	(0.003)	(0.009)	(0.035)
Treatment:Wave7	0.006	0.016	−0.031	−0.012	−0.032	−0.011*	−0.003	−0.067
	(0.019)	(0.023)	(0.016)	(0.007)	(0.024)	(0.005)	(0.009)	(0.039)
Treatment:Wave8	−0.005	−0.049*	−0.033*	−0.001	−0.049*	−0.017***	−0.004	−0.159***
	(0.021)	(0.022)	(0.015)	(0.007)	(0.024)	(0.004)	(0.011)	(0.039)
HH characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HH FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Urban wave trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.812	0.540	0.522	0.726	0.751	0.285	0.470	0.527
Adj. R^2	0.727	0.331	0.304	0.601	0.638	−0.041	0.230	0.313
Num. obs.	12312	12312	12312	12312	12312	12312	12312	12312
RMSE	0.209	0.304	0.149	0.054	0.266	0.082	0.084	0.475
N Clusters	3827	3827	3827	3827	3827	3827	3827	3827

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Note: Household characteristics include age, Age, Gender, Marital status and Education of household head, Household size, Urban or not, The number of rooms, and Housing ownership. Standard errors are clustered at the household level.

Table 9: Event study analysis on changes in cooking fuel choice between treated and control districts in Uganda.

	Firewood (1)	Crop residue (2)	Kerosen (3)	Charcoal (4)	Solar (5)	Electricity (6)	Num. fuels (7)
Treatment:Wave5	−0.002	0.005	−0.040	0.004	0.008	−0.006	−0.031
	(0.005)	(0.003)	(0.029)	(0.003)	(0.017)	(0.017)	(0.032)
Treatment:Wave7	0.010*	−0.000	−0.021	0.001	−0.022	−0.006	−0.039
	(0.005)	(0.003)	(0.032)	(0.002)	(0.027)	(0.021)	(0.035)
Treatment:Wave8	0.011*	−0.005	−0.037	0.002	−0.049	0.031	−0.047
	(0.005)	(0.003)	(0.031)	(0.002)	(0.029)	(0.022)	(0.034)
HH characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HH FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Urban wave trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.630	0.503	0.642	0.285	0.606	0.786	0.524
Adj. R^2	0.462	0.277	0.479	−0.040	0.426	0.689	0.307
Num. obs.	12312	12312	12312	12312	12312	12312	12312
RMSE	0.123	0.082	0.356	0.029	0.321	0.193	0.441
N Clusters	3827	3827	3827	3827	3827	3827	3827

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Note: Household characteristics include age, Age, Gender, Marital status and Education of household head, Household size, Urban or not, The number of rooms, and Housing ownership. Standard errors are clustered at the household level.

Table 10: Event study analysis on changes in lighting fuel choice between treated and control districts in Uganda.

	Grid (1)	Solar panel (2)
Treatment:Wave5	−0.005	0.005
	(0.016)	(0.018)
Treatment:Wave7	0.016	−0.019
	(0.018)	(0.026)
Treatment:Wave8	0.027	−0.035
	(0.020)	(0.029)
HH characteristics	Yes	Yes
Wave FE	Yes	Yes
HH FE	Yes	Yes
Urban wave trend	Yes	Yes
R^2	0.837	0.613
Adj. R^2	0.763	0.437
Num. obs.	12312	12296
RMSE	0.176	0.320
N Clusters	3827	3826

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Note: Household characteristics include age, Age, Gender, Marital status and Education of household head, Household size, Urban or not, The number of rooms, and Housing ownership. Standard errors are clustered at the household level.

Table 11: Event study analysis on the impact of the 2016 earthquake on household access to grid electricity and solar panel ownership in Uganda.

	Firewood (1)	Crop residue (2)	Kerosen (3)	LPG (4)	Charcoal (5)	Solar (6)	Electricity (7)	Num. fuels (8)
Treatment:Wave5	0.004	0.064^{**}	0.004	−0.006	−0.033	−0.006	−0.003	0.026
	(0.017)	(0.021)	(0.015)	(0.004)	(0.024)	(0.003)	(0.008)	(0.038)
Treatment:Wave7	0.008	0.027	-0.032^{*}	−0.008	−0.039	-0.014^{**}	0.001	−0.057
	(0.020)	(0.027)	(0.016)	(0.006)	(0.025)	(0.005)	(0.008)	(0.042)
Treatment:Wave8	0.003	-0.068^{*}	-0.033^{*}	0.004	-0.065^{*}	-0.020^{***}	0.005	-0.176^{***}
	(0.022)	(0.027)	(0.014)	(0.006)	(0.026)	(0.005)	(0.010)	(0.044)
HH characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HH FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Urban wave trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.796	0.531	0.498	0.716	0.745	0.290	0.423	0.506
Adj. R^2	0.709	0.332	0.285	0.596	0.636	−0.011	0.178	0.297
Num. obs.	8441	8441	8441	8441	8441	8441	8441	8441
RMSE	0.211	0.341	0.146	0.055	0.266	0.084	0.084	0.507
N Clusters	2495	2495	2495	2495	2495	2495	2495	2495

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Note: Household characteristics include age, Age, Gender, Marital status and Education of household head, Household size, Urban or not, The number of rooms, and Housing ownership. Standard errors are clustered at the household level.

Table 12: Event study analysis on changes in cooking fuel choice between treated and control districts in Uganda. Control group = Northern and Eastern region

	Firewood (1)	Crop residue (2)	Kerosen (3)	Charcoal (4)	Solar (5)	Electricity (6)	Num. fuels (7)
Treatment:Wave5	-0.001	0.007	-0.044	0.002	0.006	-0.007	-0.037
	(0.007)	(0.004)	(0.031)	(0.002)	(0.019)	(0.017)	(0.034)
Treatment:Wave7	0.014	-0.001	-0.067^{*}	-0.001	0.006	0.008	-0.041
	(0.007)	(0.005)	(0.034)	(0.001)	(0.030)	(0.020)	(0.038)
Treatment:Wave8	0.017^{*}	-0.009	-0.093^{**}	-0.000	-0.024	0.043^{*}	-0.067
	(0.007)	(0.005)	(0.033)	(0.001)	(0.032)	(0.021)	(0.037)
HH characteristics	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Wave FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
HH FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Urban wave trend	Yes	Yes	Yes	Yes	Yes	Yes	Yes
R^2	0.650	0.502	0.639	0.303	0.579	0.778	0.523
Adj. R^2	0.501	0.290	0.485	0.006	0.400	0.684	0.320
Num. obs.	8441	8441	8441	8441	8441	8441	8441
RMSE	0.138	0.098	0.351	0.024	0.320	0.187	0.459
N Clusters	2495	2495	2495	2495	2495	2495	2495

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Note: Household characteristics include age, Age, Gender, Marital status and Education of household head, Household size, Urban or not, The number of rooms, and Housing ownership. Standard errors are clustered at the household level.

Table 13: Event study analysis on changes in cooking fuel choice between treated and control districts in Uganda. Control group = Northern and Eastern region

	Grid (1)	Solar panel (2)
Treatment:Wave5	-0.004	0.003
	(0.016)	(0.020)
Treatment:Wave7	0.021	0.003
	(0.018)	(0.029)
Treatment:Wave8	0.039^{*}	-0.014
	(0.019)	(0.032)
HH characteristics	Yes	Yes
Wave FE	Yes	Yes
HH FE	Yes	Yes
Urban wave trend	Yes	Yes
R^2	0.838	0.597
Adj. R^2	0.769	0.426
Num. obs.	8441	8432
RMSE	0.168	0.318
N Clusters	2495	2494

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Note: Household characteristics include age, Age, Gender, Marital status and Education of household head, Household size, Urban or not, The number of rooms, and Housing ownership. Standard errors are clustered at the household level.

Table 14: Event study analysis on changes in household access to grid electricity and solar panel ownership between treated and control districts in Uganda.
Control group = Northern and Eastern region

Acknowledgements

I wish to thank Yasuyuki Sawada for his supervision throughout the entire process of developing this paper. I would also like to express my appreciation to Atusuki Kotani, Chinatsu Itoi, Chisato Tachibana, Dan Alexander Jimenez, Donnie Osborne, Jincao Ma, Linqian Zhang, Mahiro Kobayashi, Hao Luo, Soyoka Okamura, Sujeong Kim, Tomoki nishiyama, Yaolamg Zhong, Yutaro Nakai, and Ze Wang. For the members of Sawada Seminar 2024 and 2025, the University of Tokyo, I think we could enhance each other in weekly seminars. I express my gratitude to all of you.