Credit, LPG Stove Adoption and Charcoal Consumption: Evidence from a Randomised Controlled Trial*

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Abstract

The high start-up cost of modern cooking appliances has been shown to be the key factor that hinders transition of households from biomass energy to clean energy in developing countries. We designed a randomised controlled trial to identify the impact of relaxing households' liquidity constraints on LPG stove adoption and charcoal use in urban Tanzania. In collaboration with a local micro-finance institution, we randomly assigned households into a subsidy treatment and a credit treatment, which included different repayment arrangements. We show that relative to households in the control group, adoption of LPG stoves reduced charcoal use by 47.5% in the treated group. However, providing subsidies for stove purchases resulted in a much larger reduction in charcoal use (54%) than did providing access to credit (41%). We highlight the importance of relaxing households' financial constraints and improving access to credit to encourage urban households to switch to clean energy sources and save the remaining forest resources of Africa.

JEL Classification: G21, G31, O10, O13, Q23, Q51.

Keywords: Charcoal, LPG Stoves, Deforestation, Liquidity Constraint, Credit

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1 Introduction

Charcoal is the main source of cooking energy for households in urban areas of many Sub-Saharan (SSA) countries (Campbell et al., 2007; Mercer et al., 2011). In the urban parts of Tanzania - the country we focus in this paper - the proportion of households that use charcoal to meet their main cooking needs increased from 47 percent in 2001 to 71 percent in 2007, and a single city Dar es Salaam alone consumes 500,000 tones of charcoal, half of the total annual charcoal consumption of the country (World Bank, 2009). On the other hand, many SSA countries have been experiencing economic growth which resulted in increased income and living standard in urban areas (AfDB, 2014). The fact that charcoal consumption has been increasing with increase in income is contrary to the predictions of the "energy ladder hypothesis", which has been the key theory in explaining energy transition in developing and emerging countries (Heltberg, 2005; Masera et al. 2000). This theory postulates that households consume biomass fuels such as fuelwood and charcoal at lower levels of income and switch to modern fuels such as kerosene, natural gas, and electricity as their income increases. In this paper, we use a novel randomised controlled trial (RCT) to shed light on the key factors that let households in urban areas of Africa shift from charcoal to Liquified Petrolium Gas (LPG).

Using biomass fuels such as charcoal has serious environmental, health, and climatic implications. The use of charcoal for cooking in urban areas and firewood in rural areas of SSA has been a prime cause of deforestation and forest degradation (Campbell et al., 2007; Brown and Bird, 2008; Mercer et al., 2011), clearly resulting in loss of irreplaceble biodiversity and degradation of local ecosystems (Allen and Barnes, 1985; Geist and Lambin, 2002; Hofstad et al., 2009; Köhlin et al., 2011). Biomass fuelwood use is also associated with indoor air pollution, which claims 3.3% of the global burden of disease, especially that of women and children and about 2 million premature deaths per year WHO (2009). Recent studies also documented that biomass fuel use, often burned in inefficient cookstoves, contributes to climate change through its emission of harmful greenhouse gases including black carbon and carbon dioxide (Sagar and Kartha, 2007; Kandlikar, et al. 2009; Grieshop et al., 2011).

Transition to cleaner fuels is conditional on adoption of appropriate cooking appliances, which can have significant financial implications on poor households who will forgo consumption of other items to acquire them (Edward and Langpap, 2005; Lewis and Pattanayak, 2012). Using carefully executed randomised controlled trials, a few studies (Smith-Sivertsen, 2009; Hanna et al. 2012; Miller and Mobarak, 2013) investigated the factors that promote adoption of improved biomass cookstoves and their impact on indoor air quality, health, and fuelwood consumption in rural areas of developing countries. These studies identify social networks, availability of continuous technical support, cultural factors, and good designs that meet households' expectations as important factors that promote the adoption and continued use of improved biomass cookstoves. The few existing studies focusing on adoption of modern (clean) cookstoves use observational data (e.g., Edward and Langpap, 2005; Alem et al. 2014) and identify high start-up cost as the key factor that hinders households from switching to appliances that use clean energy such as LPG stoves.

The key question is then whether helping urban households to relax liquidity constraints can

make them switch to modern cookstoves, or whether such dependence on charcoal for cooking is driven by cultural factors that can not be altered by public policy in the short-run. In this paper, we provide the first rigorous evidence on the causal effects of relaxing households' liquidity constraints on adoption of LPG stoves and on charcoal consumption. We collaborated with Tanzania's largest micro-finance institution (WAT-SACCO) and randomly allocated households in Dar es Salaam, the largest city in the country, into a "purchase on subsidy" treatment and "purchase on credit" treatment, which constituted three types of credit schemes (payback daily, payback weekly and payback monthly) repayable in six months. To the best of our knowledge, this paper is the first to provide rigorous evidence on the impact of relaxing liquidity constraint of households on adoption of high-cost cooking appliances and on charcoal consumption.

We take advantage of our randomised design to estimate the impact of adoption of LPG stoves through subsidy and the three types of credit schemes on charcoal consumption. Our results indicate that LPG stove adoption overall resulted in a significant reduction in total charcoal use by the treatment group. Specifically, average treatment effects on the treated (ATT) estimates indicate that households in treated communities consumed 47 percent less charcoal compared to the control group four months after the program has been rolled out. This amounted in a reduction in charcoal consumption from 19 kg/week at the baseline to 13 kg/week during the follow-up. However, we find a much larger (54%) reduction in charcoal consumption by households who adopted LPG stoves through subsidy compared to those who acquired them through credit (41%).

Africa's tropical forests have significant carbon sequestration capacity but are at greater risk than those in other parts of the world, disappearing three times faster than the world average (Mercer et al. 2011).[1] Our findings have significant implications for policies that aim at promoting transition of households to clean energy sources, and saving the remaining forest resources of the continent. Given reducing the startup cost of LGP stoves has significant impact on their adoption and consequently on charcoal use, governments, international donor agencies and other stakeholders should consider channeling resources to improve affordability of LPG stoves to the poor.

The rest of the paper is structured as follows. The next section describes the study area, experimental set-up, and timeline. Section 3 presents descriptive statistics of key variables for both the treatment and control groups. Section 4 presents experimental results on the impact of LPG stove adoption on charcoal consumption, the key outcome variable of interest. Finally section 5 concludes the paper.

2 Experimental Design

2.1 Study Area

Our study was conducted in Kinondoni and Temeke, two of the three districts of Dar es Salaam, the largest city of Tanzania. These two districts are located at the two extreme ends of the city, separated in between by Ilala, a third district. Ilala, which we used for the pilot, is the smallest

[1] The study by Mercer et al. (2011) actually documents that 30 million ha of Africa's forest, an area equivalent to the size of Finland, was deforested during 2000-2010, 80% of which was for energy consumption.

district both in terms of geographical size and population.[2] Dar es Salaam is the most populous region in Tanzania (with nearly 5 million people) and over 70% of its population uses charcoal as their main source of cooking fuel (NPS 2012). The heavy reliance on charcoal is evident from the open charcoal markets spread throughout the city. Approximately 1 million tonnes of charcoal is consumed for cooking in Tanzania annually and Dar es Salaam city alone consumes half of this amount (World Bank, 2009).

Tanzania has recently discovered huge reserves of natural gas that is expected to play a significant role in the country's economy by transforming the energy sector and boosting the gross domestic product.[3] Since 2010, several offshore natural gas discoveries have been made by the BG Group in partnership with Ophir Energy, and Statoil in partnership with Exxon Mobil, reaching around 30 trillion cubic feet of recoverable natural gas reserve. With more discoveries envisaged, a pipeline has been constructed to transport natural gas from Mnazi Bay (the central point of discovery) to Dar es Salaam. These discoveries are expected to significantly reduce the cost of gas and electric energy and create the incentive for households to switch away from charcoal to meet cooking energy needs. However, this transition could be significantly constrained by the relatively high startup cost of modern cooking appliances, especially by the poor households. Findings from the baseline survey, which we present in the next sections support this skepticism. Almost all (99 percent) of households we surveyed stated high level of awareness about LPG stoves and their benefits but felt constrained to not adopt, mainly by the their high initial cost.[4]

Our study is conducted at an important time to provide useful and policy relevant evidence on the constraints of households to adopt modern cookstoves and switch away from charcoal and, what roles public policy can play to tackle them. Given the similarities of many Sub-Saharan African countries with Tanzania in terms of access to energy, the findings from this study will also have significant relevance to other African countries.

2.2 Sample Selection and Design

In order to conduct our experiment, we chose two wards from each of Temeke and Ilala districts, from a total of 34 and 30 wards respectively. We chose Sandali and Azimio wards from Temeke district, and Manzese and Mwananyamala wards from Kinondoni. The selected wards are residences for a majority of the low income urban households in Dar es Salaam and share similar socioeconomic characteristics but distantly located from each other. The wards benefited reasonably equally from the Community Infrastructure Upgrading Program (CIUP) implemented by the Dar es Salaam city council between 2005-2010. The program involved improving quality of roads, footpaths, drainage, sanitation, solid waste, street lightning, public toilets and drinking water (URT, 2004; URT, 2010).

We approached ward secretaries - government officials responsible for administrating wards under districts - to provide us with the list of all sub-wards, the lowest administrative units in urban areas (also known as streets) ranked by the average economic status of resident households.

[2] See map of Dar es Salaam in the appendix.

[3] http://allafrica.com/stories/201504030134.html.

[4] Currently, less that 4 percent of households in urban Tanzania own a modern cooking stoves such as electric or gas stoves (NPS 2012).

We then selected the top four streets in their rankings in terms of economic status from each ward to participate in our study, which gave us a total of 16 streets. The key argument for selecting households this way is the fact that re-filling LPG gas once the startup gas runs out requires a bulk purchase (as opposed to low cost daily purchase for charcoal, which is common in the city) and thus the targeted population should be able to afford such costs. Finally, we asked the 16 sub-ward leaders to prepare the roster of eligible households in their streets from which we randomly selected a total of 722 households who participated in the baseline survey. Eligibility criteria required that the selected households never owned/used an LPG stove and use charcoal (but not kerosene) as their main source of cooking energy.[5]

In order to minimise contamination (spill-over effects from treatment groups to the control group), we assigned treatments at street (sub-ward) level. The sampled streets are scattered across the districts and are reasonably large by geographical size and demographics, with average number of households in the sampled streets being about 3000. Street-level randomization also makes implementation of the program relatively easier as it seems fair from households point of view, and politically acceptable by ward leaders. It is therefore important to note that our randomization is done at street-level but the outcome variables of interest are measured at household level.

We are interested in answering three key research questions: first, we want to identify the impact of LPG stoves (regardless of their mode of acquisition) on charcoal consumption, the key outcome variable of interest; second, we are interested in exploring whether the impact on charcoal consumption is different depending on the mode of acquisition (subsidy or credit); and third, we want to assess the degree of stove use and satisfaction in the stoves by households under the two treatments. We thus randomly assigned 5 streets into the credit treatment, 4 streets into the subsidy treatment and kept the remaining 8 streets as the control group. As a result, 216 households were potentially assigned to the credit treatment, 209 to the subsidy treatment and 299 to the control group.

2.3 Timeline and Implementation

We obtained a research permit for this project from the office of Dar es Salaam Regional and Districts Administrative Secretaries, and implemented a fact-finding survey in October-November 2014 on 40 urban households. The aim of this survey was to document both qualitative and quantitative background information on knowledge, adoption and usage (and non-usage) of both LPG and charcoal stoves in all districts, important information that we later use to design our interventions. We designed a short questionnaire and conducted a few focus group discussion sessions that allowed us to obtain informative responses. At this stage, we also included a set of questions on households' maximum willingness to pay for an LPG stove package and whether they would like to have the stove package on subsidy or on credit and pay for it bit by bit over a certain period. We found encouraging responses from households on knowledge and willingness to adopt LPG stoves, either on credit or subsidy programs. We also found that high start-up cost seemed to be the main factor that hindered households from acquiring the stove.

[5]The proportion of households that use kerosene gas in Dar es Salaam is only about 7.8% (NBS 2012).

We conducted a comprehensive baseline survey during March-April, 2015 covering all the 722 sampled households in the 16 sub-wards. In the baseline we included questions on demographic and other socio-economic characteristics, cooking habits, stove use, and awareness and willingness to pay for LPG stoves. This was important information given that the cost of acquiring the stove package is reasonably high and it is natural that some households may not be willing to buy it either on credit or on subsidy. In addition to household-level information, we collected community-level information such as distance to the nearest charcoal market, access to roads etc.

In early May 2015, we conducted a pre-intervention survey to check whether the households who were assigned to the treatment group were willing to buy the LPG stove. During this time, we informed the treatment group that their household has been one of the randomly selected households to receive an LPG stove on subsidy or credit and that the stoves were planned to be delivered approximately 1-2 weeks after the pre-intervention survey. The households were then asked whether they would like to be a part of the program. Only 296 households of the 425 households who were randomly chosen to participate in the program agreed to purchase the stoves, and the remaining 129 households (30%) declined to participate. We later check whether such a refusals to uptake the stoves are likely to bias our sample.

We implemented the LPG stove program in collaboration with a Saving and Credit Cooperative (SACCO) named "Women Advancement Trust" (WAT) which helped us with handling the delivery of the stoves and collection of repayment instalments for the credit treatment households. WAT SACCO is one of the fast growing saving and credit cooperatives that are working to provide access to micro-finance for the urban poor. So far, WAT has gained good reputation and credibility in disbursement and handling of different types of loans including micro credit to finance the purchase of home appliances.[6] In order to make the loan credible and minimize the default rate, we followed all procedures for getting such loans as per the rules of the SACCO , but with a few modifications to suit to the objectives of this study. For example, we did not require households to present any other physical asset as collateral rather than the stove itself. In addition, all credit treatment households were required to pay TZS 20,000 (i.e. 10% of total loan) upfront as their initial re-payment on the day of stove delivery. In addition, they were required to provide a letter of guarantee from from their local government offices, which in Tanzanian context is credible.

The intervention was implemented in late May, 2015. All households selected for the treatments were invited for training before they were handed in the full package LPG stove. The training included instructions on how to safely use, clean, maintain and re-fill the LPG stoves once the startup gas runs out. Households under the credit treatment were provided extra instructions regarding their specific credit scheme including: how to fill-in the application forms, the required documents, how the payments will be collected, etc. All participants were allowed to ask as many questions as they wished and answers were given by the survey team. To minimize associated transaction costs and inconveniences, we required households receiving the stoves on credit to transfer the repayment instalments to a given mobile phone account managed by WAT using their mobile phone banking system. The transfers were set to be done during the working hours of either each working day of the week, every Monday of the week or every 30th day of the month, depending

[6]See "http://watsaccos.co.tz" for more information about WAT SACCO.

on the treatment type. The complete loan repayment period was set to be 6 months after delivery of the stove with repayment rates of either TZS 33,350 per month, TZS 8,350 per week or TZS 1,200 per day, depending on the treatment type. We did not charge any interest fee on the loans but required beneficery households to cover minor transaction fees charged by mobile phone companies during loan repayment.

We then conducted a midline follow-up survey at the end of September 2015 - approximately four months after the stoves have been distributed - to collect information on key outcome variables of interest including charcoal consumption, LPG stove use, compliance to treatment, and satisfaction with the stoves.[7]

3 Data and Descriptive Statistics

Table 1 presents descriptive statistics of key household socio-economic characteristics, cooking pattern, charcoal use and stated demand for LPG stoves at the baseline. Panel A shows that the average age of the household head is 48 years, the majority of whom (67%) are male, and the average education is 7.1 years of schooling, being slightly higher than the standard primary school level in Tanzania, which is 7 years. About half of the sample households live in privately owned households, but only 41% have access to a separate private kitchen, the remaining either cooking on their corridors or sharing a kitchen with other households. Consistent with our expectation, the majority of our sample households are low income urban dwellers with average reported mean annual income of TZS 309,000 (about USD 172).[8] We however notice that the reported average daily expenditure on basic consumption items is TZS 9,600, which on annual basis is nearly eleven times larger than the reported income. This overwhelming difference provides additional evidence that compared to consumption expenditure, income in developing countries is significantly underreported (Deaton, 1997; Deaton and Grosh, 2000). In our subsequent analysis we rely on consumption expenditure to capture economic status of households.

Table 1 about here

There is a large dependence on charcoal to meet cooking energy needs by households in urban Tanzania (Panel B). The average household cooked using charcoal for about 24 years and consumes 18.7 kg of charcoal per week, which costs about 11,000 TZS. We use insights from a recent study to shed light on the devastating consequences of charcoal use in Tanzania. Luoga et al, (2000) show that it requires one hectare of the Miombo woodland forest of Tanzania to produce approximately 3 tonns of charcoal. Using rough computation, it is easy to show that our sample of households deplete an equivalent to 0.6 ha of forest every week. When it comes to the intra-household decision on the choice of cook stoves, only 47 percent reported that the head is the main decision maker about the type of stoves to be used by the household. This suggests that on average spouses (wives) have a fairly strong intra-household bargaining power when it comes to acquisition of kitchen appliances.

[7] We initially planned to conduct the mid-line survey six months after the stoves have been distributed. However, the 2015 Tanzania National Election was scheduled in October 2015. In order to avoid interferences in our survey due to election related activities, we instead decided to conduct the mid-line survey in September 2015, four months after intervention.

[8] At the time of the baseline survey, 1 USD = 1800 TZS.

The type of meals cooked by the household could influence the amount and type of fuel used through the cooking time and taste of food. During the fact finding survey, a few respondents argued that while rice tastes better when cooked on charcoal stove, it takes significantly longer time to boil beans (the main ingredient for the complementary sauce) on the stove. Our baseline data suggests that nearly half of the sample cook rice and beans very often with about 19 meals cooked per week.

Low adoption of LPG stoves in Dar es Salaam seems to be mainly driven by liquidity constraints. Panel C of table 1 reports that 99 percent of the sample households knew about LPG stoves and 80 percent know someone who uses the stove within their close network. However, 93 percent of the the sample households reported the high startup cost of the stove package as the main constraint to their adoption, while 70 percent indicated the cost of refilling LPG gas as a challenge. Difference in taste of food cooked using LPG stoves does not seem to be an important reason for not owning LPG stoves for almost the entire sample. Only 2 percent reported it as the main reason for not owning an LPG stove. This could be partly because none of the households in our sample used an LPG stove previously so they did not experience the taste of food cooked using the stove. This number may change during the endline survey when households are asked the same question after they had experienced cooking using the LPG stove. When asked if they wish to have an LPG stove in the future, in case their economic status improves, a staggering 96% of our sample households replied "yes" but their current average willingness to pay for the stove package is only TZS 63,420, which is much lower than the market price (200,000 TZS) of the stove package in Dar es Salaam.

Randomisation of treatment should insure that on average treatment and control groups have similar baseline characteristics. In order to check this, in table 2, we present means of several key characteristics of households in both groups, as well as test results for the null hypothesis that the difference in means is statistically significantly not different from zero. For nearly all the variables presented, the difference in means is not statistically different from zero. The sole exception is that there is a statistically significant difference in the means of the variable "owning a saving account" between the credit treatment and the control group. Although this is unfortunate, we don't think it will bias our results since the proportion of households who own a saving account in the control group is about 9 percentage points higher than the credit treatment.

Table 2 about here

In order to investigate if the decision not to buy the LPG stoves by some of the treatment households resulted in a systematic difference between the treatment and control groups, we performed a simple mean comparison test for all relevant baseline characteristics. Results reported in table 3 indicate that none of the baseline variables seem to be statistically different between the treatment and control groups. Consequently, the decision not to buy by some of the potential treatment group households is less likely to create a bias in our sample.

Table 3 about here

4 Results

4.1 Charcoal Consumption

Given the randomised nature of our design, we can identify the impact of adoption of LPG stoves on charcoal consumption from the single mean differences between treatment and control groups in an OLS regression. In order to minimise measurement error, during both surveys households were asked to take a record of the quantity of charcoal used during the most recent week in the local units. We visited four charcoal markets in each ward and constructed average conversion factors to standard units by measuring each available local unit using a digital scale. We then converted all local units reported by households into standard units using these conversion factors.

We begin with results from the simple mean comparison of weekly charcoal consumption between the treatment and control groups during the baseline and follow-up as reported in Table 6. Panel A presents the results for the quantity of charcoal consumed. While the two groups reported the same consumption of charcoal per week during the baseline (19 kg), treated households consumed 6 kg less in a week compared to the control households during the follow-up survey, which we conducted four months after the stoves were introduced. This translates into a large reduction in charcoal use which is statistically significant at one percent level. We present the monetary value of the reduction in charcoal due to adoption of LPG stoves in Panel B. The results reveal that adoption of LPG stoves reduced the amount of weekly charcoal expenditure for the treatment group by about 3,800 (USD 2.1) compared to the control group.

Table 4 about here

Table 5 provides formal empirical estimation of average treatment effects on the treated (ATT) from an OLS model. Column (1) presents the results for the impact of adoption of LPG, regardless of the treatment type. In column (2), we extend the analysis by controlling for the type of treatment (subsidy and credit). This is very important from public policy point of view given the ongoing debate that people tend to value and use goods less when they receive them at a lower price (e.g., Hoffman et al, 2008; Hoffman, 2009; Cohen & Dupas, 2010). Consistent with the observation in the mean comparison presented in the previous table, column 1 of table 5 suggests that LPG adoption reduced charcoal consumption by about 47.5 percent per week compared to the treatment group. When we assess the impact by the treatment type, results in column 2 suggest relatively larger impact (54 percent) for the stoves adopted through a subsidy compared to the control group than those purchased on credit (41 percent). The results remain robust even after controlling for other covariates (column 3). We argue that the difference in the impact of LPG stoves acquired between the credit and subsidy treatments could be explained by several factors. The main reason could be the fact that we conducted our midline followup survey four months after the interventions and before households who bought the stoves on credit have paid back the full amount of the LPG loan. It is therefore plausible to expect that the credit households are still hesitant to use the stove relative to those who received the stoves on subsidy and who actually have full ownership. This could be more pronounced by the fact that the stoves themselves are collateral for the credit.

Table 5 about here

4.2 Satisfaction in LPG Stoves

In addition to identifying the impact of LPG stove adoption on charcoal use, it would be interesting to investigate how often adopter households use the stoves and whether the intensity of use differs across treatments. One could anticipate that provision of LPG stoves would encourage households to switch from charcoal to LPG. However, existing empirical evidence (e.g., Masera et al. 2000; Heltberg, 2005) suggest that households may continue to use the charcoal stove in combination with the LPG stove, a phenomenon known as "fuel stacking". In our sample, almost 25 percent of the treated households (i.e., 74 households) reported not to have used the LPG stove over the past one week during the follow-up survey.[9] In table 6, we explore if stove use and intensity is correlated with the type of treatment assigned to households. Results suggest that the number of times the stove is put in use is not correlated with the treatment category. These results are robust to controlling for other covariates. We however find education (years of schooling) to be positively correlated with the intensity of LPG stove use.

Table 6 about here

We finally explore to what extent households who received LPG stoves are satisfied with the different attributes. Figure 1 shows the distribution of responses to the satisfaction questions. Results suggest that the majority of households are satisfied with all features of the stove including, stove quality (80 percent), stove functioning (79 percent), gas cost (77 percent), food taste (73 percent) and cooking convenience (80 percent). These results indicate that the type of LPG stoves we distributed have high acceptance rate by sample of treated households in urban Tanzania.

Figure 1 about here

In order to explore the correlates of reported levels of satisfaction with the different attributes of LPG stoves, we run simple OLS models of satisfaction and report the regression results in table 7. Two variables appear to be consistently important correlates of satisfaction in LPG stoves, household size and years of schooling. Households headed by educated individuals are satisfied with all aspects the LPG stoves. Larger households are satisfied with all aspect of the stove except with functioning. We however do not find any evidence suggesting satisfaction in stove attributes is correlated with the type of treatment, as indicated by coefficient of the credit treatment variable, which is statistically insignificant.

Table 7 about here

5 Conclusions

Charcoal, largely consumed by households in urban areas, has been documented to be one of the main causes of deforestation and forest degradation in Africa. Forest clearing for charcoal production resulted in loss of invaluable biodiversity and destruction of local ecosystems. One important factor that hinders transition of households from biomass energy to clean energy sources is the high start-up cost of modern cooking appliances. In order to test for this hypothesis, we collaborated with one of Tanzania's largest micro-finance institutions, WAT-SACOS, and implemented an LPG

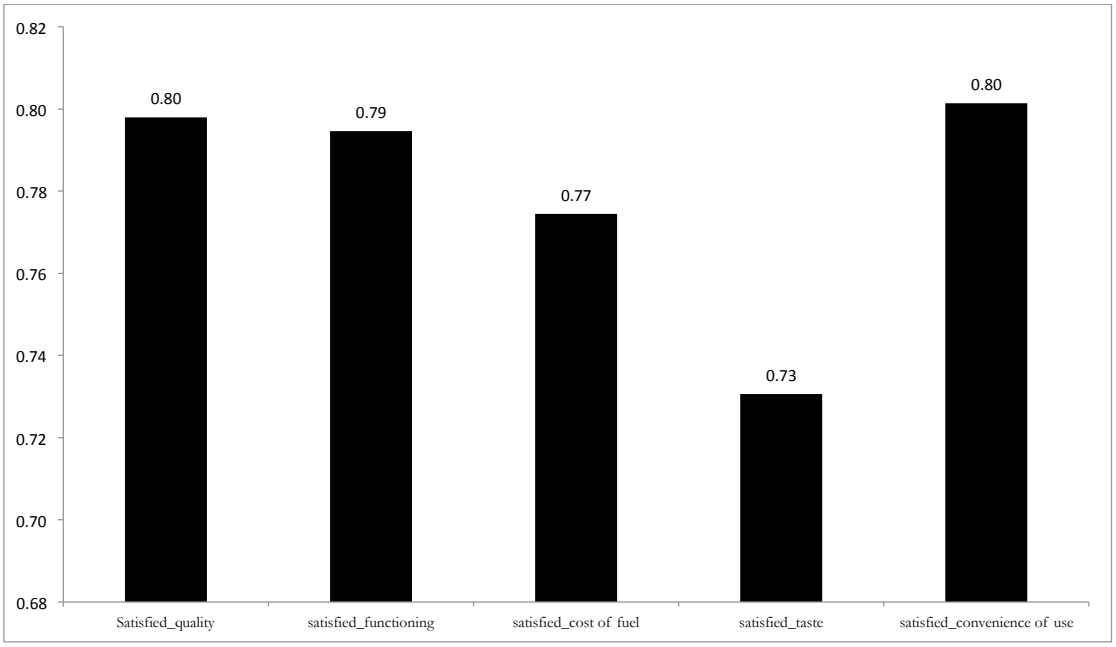
[9] See table A1 in the appendix for the distribution of reasons for not using the stoves

gas stove program in a randomised controlled trial setup. The program involved provision of a durable and high-quality two- burner LPG stove package on subsidy and credit, which included different repayment arrangements. To the best of our knowledge, this is the first study to provide rigorous evidence on the causal effects of relaxing households financial constraints on adoption of modern cooking appliances with high start-up cost and charcoal consumption.

The LPG stoves we offered had high uptake rate by urban households in Tanzania with 70 percent of those who were randomly assigned to the treatments adopting them. Our results indicate that, overall, adoption of LPG stoves reduced charcoal consumption by about 47.5 percent per week compared to the control group. When we assess the impact by the treatment type, estimates suggests that compared to the control group, those who adopted the stoves through a subsidised price reduced charcoal consumption by 54 percent while those who adopted the stoves on credit reduced charcoal consumption by 41 percent. These results are robust for controlling other household covariates. This finding is consistent with the reported use frequency by households, with those who obtained the stoves through subsidy using them more often than those who obtained them on credit. The possible explanation for the difference in stove use and impact on charcoal consumption was most likely driven by the fact that the follow-up survey took place a couple of months before the full credit amount has been paid out by households, who probably did not feel complete ownership of the LPG stoves.

Millions of hectares of Africa's forests are destroyed for production of charcoal and firewood each year. Given the documented high carbon sequestration potential of Tanzania's forests, targeting reduction of charcoal production would have a much larger external benefits to society at large. The findings from our study provide useful insights on how to reduce charcoal consumption in urban areas of Africa. Both the descriptive statistics and results from our randomised controlled trial demonstrate that the high start-up cost of modern cooking appliances such as LPG stoves is the main factor that prohibits households from switching to modern and environmental-friendly energy. In view of this, simple policy interventions such as reducing the import duty of LPG stoves could increase adoption and use of LPG stoves and consequently reduce charcoal consumption. This is the main message that originates from our study, which could be useful to policymakers, donors, and other stakeholders who are interested in saving the remaining forest resources of Africa.

Figure 1: Satisfaction with different features of LPG stoves



1.pdf

Appendix

References

- African Development Bank (AfDB) (2014). African Development Report: Regional Integration for Inclusive Growth. http://www.afdb.org/fileadmin/uploads/afdb/Documents/Publications/ADR14-ENGLISH-web.pdf
- Alem, Y., Hassen, S., & Köhlin, G. 2014. "Adoption and Disadoption of Electric Cookstoves in Urban Ethiopia: Evidence from Panel Data." Resource and Energy Economics 38: 110-124.
- Alem,Y., Eggert,H., Kocher,M., and Ruhunduka,R. 2015. "Why (field) experiments on unethical behavior are important: Comparing stated and revealed behavior." Unpublished
- Allen, J.C., Barnes, D.F. 1985. "The causes of deforestation in developing countries." Ann. Assoc. Am. Geogr 75 (2): 163?184.
- Angelsen, A. with Brockhaus, M., Kanninen, M., Sills, E., Sunderlin, W. D. and Wertz-Kanounnikoff, S., eds,. 2009. Realising REDD+: National strategy and policy options. IFOR, Bogor,Indonesia. http://www.cifor.org/publications/pdf-files/Books/BAngelsen0902.pdf
- Baron,R.E., Montgomery,D.W.,and Tuladhar,S.D.2009. "An Analysis of Black Carbon Mitigation as a Response to Climate Change" http://www.copenhagenconsensus.com/sites/default/files/ap-black-carbon-baron-montgomery-tuladhar-v.4.0.pdf
- Bertrand.M and Mullainathan.S. 2001. "Do people mean what they say? Implication for subjective survey data." Economics and Social Behavior 91(2):67-72
- Campbell, B. M., Angelsen, A., Cunningham, A., Katerere, Y., Sitoe, A., & Wunder, S. 2007. "Miombo woodlands?opportunities and barriers to sustainable forest management" CIFOR, Bogor, Indonesia. http://www. cifor. cgiar. org/miombo/docs/Campbell- Barriers and Opportunities. pdf (4th November 2008).
- Cohen. J. and Dupas.P. 2010. "Free distribution or cost-sharing? Evidence From a randomized malaria prevention experiment". The Quarterly Journal of Economics 125 (1): 1-45.
- Deaton, A. 1997. The analysis of household surveys: A microeconomic approach to development policy. Baltimore: Johns Hopkins University Press.
- Edwards, J.H.Y., Langpap, C. 2005. "Startup costs and the decision to switch from firewood to gas fuel." Land Econ 81 (4): 570?586.
- Grosh, M and Glewee,P., Eds. 2000. Designing household survey questionnaires for developing countries: Lessons from 15 years of the living standards measurement study. Volume 1. Oxford: Oxford University Press.
- Geist, H.J., Lambin, E.F. 2002. "Proximate causes and underlying driving forces of tropical deforestation." BioScience 52 (2): 143?150.?

- Grant Miller and A. Mushfiq Mobarak. 2014. "Learning about new technologies through social networks: Experimental evidence on non-traditional stoves in Bangladesh." Marketing Science 34(4): 480 ? 499.
- Grieshop, A.P, Marshall, J.D, Kandlikar, M. 2011. "Health and climate benefits of cookstove replacement options." Energy Policy 39: 7530-7542
- Hanna,R., Duflo,E., Greenstone,M. 2012. "Up in the smoke: the influence of household behavior on the long-run impact of improved cookstoves." MIT Working paper 12-10.
- Heltberg, R. 2005. "Factors Determining Household Fuel Choice in Guatemala," Environment and Development Economics 10: 337?61.
- Hoffman, V. 2009. "Intrahousehold Allocation of Free and Purchased Mosquito Nets." American Economic Review: Papers and Proceedings 99 (2):236-241
- Hoffman. V.. Barrett.C and Just. D. (2009). "Do Free Goods Stick to Poor Households? Experimental Evidence on Insecticide Treated Bednets". World Development 37 (3): 607?617.
- Köhlin, G., Sills, E.O., Pattanayak, S.K., and Wilfong, C., 2011. "Energy, Gender and Development." World Bank Policy Research Working Paper Series 5800.
- Lewis, J.J., and Pattanayak, S.K. 2012. "Who adopts improved fuels and cook stoves? A systematic review." Environ. Health Persp. 120 (5): 637?645.?
- National Bureau of Statistics (NBS). 2012. Tanzania National Panel Survey Report - Wave 2, 2010-2011. http://siteresources.worldbank.org/INTSURAGRI/Resources/7420178-1294154345427/NPS-Report-2010-2011.pdf
- Masera, O., B. Saatkamp, and D. Kammen. 2000. "From Linear Fuel Switching to Multiple Cooking Strategies: A Critique and Alternative to the Energy Ladder Model," World Development 28(12): 2083?2103.
- Mercer, B., Finighan, J., Sembres, T. and Schaefer, J. 2011. Protecting and restoring forest carbon in tropical Africa: A guide for donors and funders. Forests Philanthropy Action Network. http://files.forestsnetwork.org/FPAN+Africa+report+chapter+1+HR.pdf
- Sagar, A.D., Kartha, S. 2007. "Bioenergy and sustainable development?". Annual Review of Environment and Resources 32(1):131 167.
- Tone,S., Diaz,E., Pope, D., Lie,L.T., Diaz, A., McCracken,J.P., Bakke, P., Arana,B. Smith,K.R., and Bruce,N. 2009. "Effect of Reducing Indoor Air Pollution on Women?s Respiratory Symptoms and Lung Function: RESPIRE Guatemala Randomized Trial." American Journal of Epidemiology 170(2): 211-220.
- World Bank. 2009. "Environmental crisis or sustainable development opportunity? Transforming the charcoal sector in Tanzania." A Policy Note. The World Bank. Washington DC.

- WHO, (World Health Organization). 2009. Global Health Risks: Mortality and Burden of Disease Attributable to Major Risks. http://www.who.int/healthinfo/global-burden-disease/GlobalHealthRisks-report-full.pdf
- United Republic of Tanzania (URT). 2004. "CITY PROFILE for Dar Es Salaam.? www.dcc.go.tz
- United Republic of Tanzania (URT). 2010. "Dar es Salaam Infrastructure Development Programme." www.dcc.go.tz.

Table 1: Descriptive Statistics at Baseline

	Mean	SD
PanelA: Socioeconomic Characteristics		
Age	48,004	13,351
Male	0,670	0,470
Household size	5,768	2,222
Annual income (TZS)	309931,000	256702,700
Years of schooling	7,165	3,076
Muslim (dummy, 1= yes)	0,793	0,405
Has access to main grid electricity in the house (dummy, 1= yes)	0,750	0,433
Average household daily expenditure	9661,586	18043,120
Access to separate kitchen room (dummy, 1= yes)	0,406	0,491
Residential house in privately owned (dummy, 1= yes)	0,505	0,500
At least one member owns a saving account (dummy, 1= yes)	0,373	0,484
Panel B: Cooking Pattern and Charcoal Use		
Number of years using charcoal stove	23,748	11,662
Head decides on acquisition of stove (dummy, 1= yes)	0,469	0,499
Distance to nearest charcoal market (in minutes)	4,349	4,224
Number of meals cooked last week	18,885	3,560
Number of meals cooked last week using charcoal	16,073	4,698
Rice, main staple for the household (dummy, 1= yes)	0,477	0,500
Beans, main sauce (dummy, 1= yes)	0,551	0,498
Amount of charcoal used last week (in Kg.)	18,719	10,049
Total expenditure on charcoal last week (in TZS)	10948,030	6107,990
Panel C: Demand for LPG stoves		
Household knows about LPG stoves (dummy, 1= yes)	0,985	0,123
Knows someone using LPG stove (dummy, 1= yes)	0,803	0,398
High start up cost is main reason for not owning LPG (dummy, 1= yes)	0,934	0,249
Higher cost of refillingis main reason for not owning LPG (dummy, 1= yes)	0,701	0,458
Difference in taste of food cooked is main reason for not owning LPG (dummy, 1= yes)	0,024	0,152
Household wishes to own LPG stove in the future (dummy, 1= yes)	0,961	0,193
Maximum willingness to pay for an LPG stove package (TZS)	63419,670	38548,520
Affords gas refilling cost (dummy, 1= yes)	0,882	0,323
Walking distance to the nearest LPG gas dealer (in minutes)	17,757	14,102
Observations	722	

Table 2: Descriptive Statistics by Treatment Type

	[1 - Credit]		[2 - Subsidy]		[3 - Control]		[Diff. 1 Vs 3]	[Diff. 2 Vs 3]
PanelA: Socioeconomic Characteristics								
Age	47,769	12,718	47,048	11,974	47,451	12,802	0,317	-0,403
Male	0,694	0,462	0,660	0,475	0,717	0,451	-0,023	-0,057
Household size	5,644	2,039	5,799	2,236	5,997	2,258	-0,353	-0,198
Annual income in TZS (log)	12,486	0,729	12,427	0,738	12,496	0,695	-0,010	-0,069
Years of schooling	7,602	3,261	7,565	3,022	7,404	2,711	0,198	0,161
Access to main grid electricity (dummy, 1= yes)	0,745	0,437	0,809	0,394	0,811	0,392	-0,066	-0,003
Average household daily expenditure	8877,315	5968,327	10545,450	13892,930	9168,350	6438,137	-291,035	1377,100
Separate kitchen (dummy, 1= yes)	0,421	0,495	0,368	0,484	0,421	0,495	0,000	-0,052
Residential house privately owned (dummy, 1= yes)	0,472	0,500	0,483	0,501	0,515	0,501	-0,043	-0,032
Saving account (dummy, 1= yes)	0,366	0,483	0,469	0,500	0,458	0,499	-0,092**	0,011
Panel B: Cooking Pattern and Charcoal Use								
Number of years using charcoal stove	23,736	11,169	22,737	10,862	22,987	10,814	0,750	-0,250
Head decides on acquisition of stove (dummy, 1= yes)	0,472	0,500	0,435	0,497	0,421	0,495	0,051	0,015
Distance to nearest charcoal market (in minutes)	4,512	4,125	4,696	3,902	4,236	4,752	0,276	0,460
Number of meals cooked last week	19,222	3,105	19,364	3,344	19,121	3,492	0,101	0,242
Number of meals cooked last week using charcoal	16,759	4,136	16,292	4,892	16,364	4,654	0,396	-0,072
Rice, main staple for the household (dummy, 1= yes)	0,537	0,500	0,502	0,501	0,488	0,501	0,049	0,014
Beans, main sauce (dummy, 1= yes)	0,560	0,498	0,488	0,501	0,522	0,500	0,038	-0,034
Amount of charcoal used last week (in Kg.)	19,088	8,942	18,482	9,043	19,734	11,735	-0,646	-1,252
Total expenditure on charcoal last week (in TZS)	11137,440	5191,617	10804,530	4921,571	11498,890	7474,942	-361,450	-694,360
Panel C: Demand for LPG stoves								
Household knows about LPG stoves (dummy, 1= yes)	0,981	0,135	0,990	0,098	0,983	0,129	-0,002	0,007
Knows someone using LPG stove (dummy, 1= yes)	0,819	0,386	0,804	0,398	0,791	0,407	0,028	0,013
High start up cost of LPG (dummy, 1= yes)	0,949	0,220	0,914	0,281	0,936	0,245	0,013	-0,022
High cost of refilling (dummy, 1= yes)	0,704	0,458	0,699	0,460	0,700	0,459	0,003	-0,002
Difference in taste of food (dummy, 1= yes)	0,037	0,189	0,014	0,119	0,020	0,141	0,017	-0,006
Max. willingness to pay for an LPG stove (TZS)	64199,070	37458,220	67263,160	36888,770	60148,150	40281,420	4050,920	7115,010
Affords gas refilling cost (dummy, 1= yes)	0,889	0,315	0,904	0,295	0,862	0,346	0,027	0,042
Distance to the nearest LPG gas dealer (in minutes)	18,951	15,113	16,145	12,919	18,022	14,081	0,930	-1,876
Observations	216		209		297			

Notes: $***p < 0.01, **p < 0.05, *p < 0.1$.

Table 3: Descriptive Statistics by Treatment Type: Accounting for Uptake

	[Treatment]		[Control]		[Diff.]
	Coeff.	SE	Coeff.	SE	Coeff.
Panel A: Socioeconomic Characteristics Age	47,236	12,183	47,505	12,812	-0,269
Male	0,661	0,474	0,721	0,449	-0,060
Household size	5,712	2,173	5,997	2,258	-0,284
Annual income in TZS (log)	12,494	0,733	12,495	0,696	0,000
Years of schooling	7,642	3,127	7,404	2,711	0,238
Average household daily expenditure	10321,920	12560,680	9168,350	6438,137	1153,570
Separate kitchen (dummy, 1= yes)	0,411	0,493	0,421	0,495	-0,010
Residential house privately owned (dummy, 1= yes)	0,466	0,500	0,515	0,501	-0,049
Saving account (dummy, 1= yes)	0,462	0,499	0,458	0,499	0,004
Panel B: Cooking Pattern and Charcoal Use					
Number of years using charcoal stove	24,007	11,516	22,987	10,814	1,020
Head decides on aquisition of stove (dummy, 1= yes)	0,466	0,500	0,421	0,495	0,045
Distance to nearest charcoal market (in minutes)	4,945	4,060	4,236	4,752	0,710
Number of meals cooked last week	19,301	3,303	19,121	3,492	0,180
Number of meals cooked using charcoal	16,356	4,596	16,364	4,654	-0,007
Rice, main staple for the household (dummy, 1= yes)	0,497	0,501	0,488	0,501	0,008
Beans, main sauce (dummy, 1= yes)	0,476	0,500	0,522	0,500	-0,046
Amount of charcoal used last week (in Kg.)	19,193	8,781	19,734	11,735	-0,541
Total expenditure on charcoal last week (in TZS)	11072,760	4821,808	11498,890	7474,942	-426,130
Panel C: Demand for LPG stoves					
Household knows about LPG stoves (dummy, 1= yes)	0,983	0,130	0,983	0,129	0,000
Knows someone using LPG stove (dummy, 1= yes)	0,818	0,386	0,791	0,407	0,027
High start up cost of LPG (dummy, 1= yes)	0,921	0,270	0,936	0,245	-0,015
High cost of refilling (dummy, 1= yes)	0,719	0,450	0,700	0,459	0,019
Difference in taste of food (dummy, 1= yes)	0,031	0,173	0,020	0,141	0,011
Distance to the nearest gas dealer	17,836	14,423	18,022	14,081	-0,186
Observations	296		297		

Notes: $***p < 0.01, **p < 0.05, *p < 0.1$.

Table 4: Charcoal Consumption at Baseline and Follow-up, Treatment and Control Group

	[Baseline]		[Follow-up]		[Diff.]		
	Mean	SD	Mean	SD	Mean	SD	Obs.
Panel A: Amount of Charcoal in KG.							
Treated	19,24	9,18	13,52	17,33	-5,72	1,14	296
Control	19,40	11,70	19,71	10,02	-0,31	0,87	314
Diff	-0,16	0,85	-6,19 ***	1,14			
Panel B: Value of Charcoal in TZS							
Treated	11112,86	5163,02	8354,46	6541,76	2758,41	483,57	296
Control	11279,09	7455,48	12125,99	7191,85	-846,90	584,59	314
Diff	-166	522	-3772***	558			

Notes: $***p < 0.01, **p < 0.05, *p < 0.1$.

Table 5: Impact of LPG Stoves on Charcoal Consumption

	[1]	[2]	[3]
	[Charcoal/Week - kg (log)]	[Charcoal/Week - kg (log)]	[Charcoal/Week - kg (log)]
Treatment	-0.475***		
	(0.0881)		
Credit Treatment		-0.414***	-0.384***
		(0.0938)	(0.0783)
Subsidy Treatment		-0.541***	-0.527***
		(0.134)	(0.126)
Intercept	2.899***	2.899***	2.784***
	(0.0369)	(0.0369)	(0.248)
Controls	No	No	Yes
Observations	593	593	593
R-squared	0.091	0.094	0.122

Notes: $***p < 0.01, **p < 0.05, *p < 0.1$.

Table 6: LPG Stove Use: OLS Regression Results

	LPG Use	LPG Use
Credit Treatment	-1.126	-1.159
	(1.205)	(1.105)
Age		0.0268
		(0.0486)
Household size		0.315
		(0.306)
Years of schooling		0.445*
		(0.219)
Male		-0.837
		(0.686)
Separate kitchen (dummy, 1= yes)		-1.135
		(0.991)
Residential house privately owned (dummy, 1= yes)		-1.526
		(1.072)
Number of years using charcoal stove		-0.0414
		(0.0375)
Head decides on acquisition of stove (dummy, 1= yes)		1.295
		(1.195)
Number of meals cooked last week		-0.0388
		(0.176)
Intercept	12.03***	8.446*
	(0.669)	(3.952)
Observations	296	296
R-squared	0.005	0.059

Notes: Standard errors clustered at the street level, $***p < 0.01, **p < 0.05, *p < 0.1$.

Table 7: Satisfaction With LPG Stoves: Probit Regression Results

	Quality	Functioning	Food Taste	Cost	Convenience
Credit Treatment	-0.273	-0.309	-0.142	-0.237	-0.250
	(0.248)	(0.228)	(0.212)	(0.212)	(0.217)
Age	-0.00510	-0.000919	0.000793	0.00441	-0.00177
	(0.00755)	(0.00751)	(0.00967)	(0.00683)	(0.00808)
Household size	0.0795*	0.0448	0.0839*	0.0416	0.0878***
	(0.0408)	(0.0379)	(0.0476)	(0.0368)	(0.0290)
Years of schooling	0.0756**	0.0800**	0.0998***	0.0718*	0.0789**
	(0.0327)	(0.0318)	(0.0327)	(0.0416)	(0.0322)
Male	-0.366*	-0.374	-0.267	-0.407*	-0.435*
	(0.205)	(0.256)	(0.262)	(0.245)	(0.247)
Separate kitchen	-0.0582	-0.0119	-0.00106	0.107	0.0527
	(0.222)	(0.234)	(0.187)	(0.229)	(0.221)
Residential house privately owned	-0.266	-0.243	-0.196	-0.286	-0.223
	(0.183)	(0.220)	(0.186)	(0.189)	(0.190)
Number of years using charcoal stove	0.00779	-0.000186	-0.00815	-0.000188	-0.00395
	(0.00818)	(0.00807)	(0.00803)	(0.00808)	(0.00809)
Head decides on acquisition of stove	0.0683	0.0123	0.119	-0.0531	0.0111
	(0.286)	(0.281)	(0.228)	(0.261)	(0.265)
Number of meals cooked last week	-0.00608	-0.00579	0.000139	-0.00231	0.0111
	(0.0267)	(0.0300)	(0.0248)	(0.0339)	(0.0315)
Intercept	0.542	0.689	-0.138	0.351	0.264
	(0.671)	(0.716)	(0.638)	(0.833)	(0.823)
Observations	296	296	296	296	296
Pseudo R^2 - squared	0.065	0.061	0.066	0.049	0.065

Notes: Robustness standard errors in parentheses, $***p < 0.01, **p < 0.05, *p < 0.1$.

Table A1 Reasons for not using LPG Stoves

	No.	%
Gas run out	5	0,07
Stove/parts mulfunction	3	0,04
Type of food cooked	2	0,03
Not confident on how to operate the stove	4	0,05
Non of the above	60	0,81
Observations	74	1,00

Figure 1: Map of Dar Es Salaam City Council Showing Municipalities

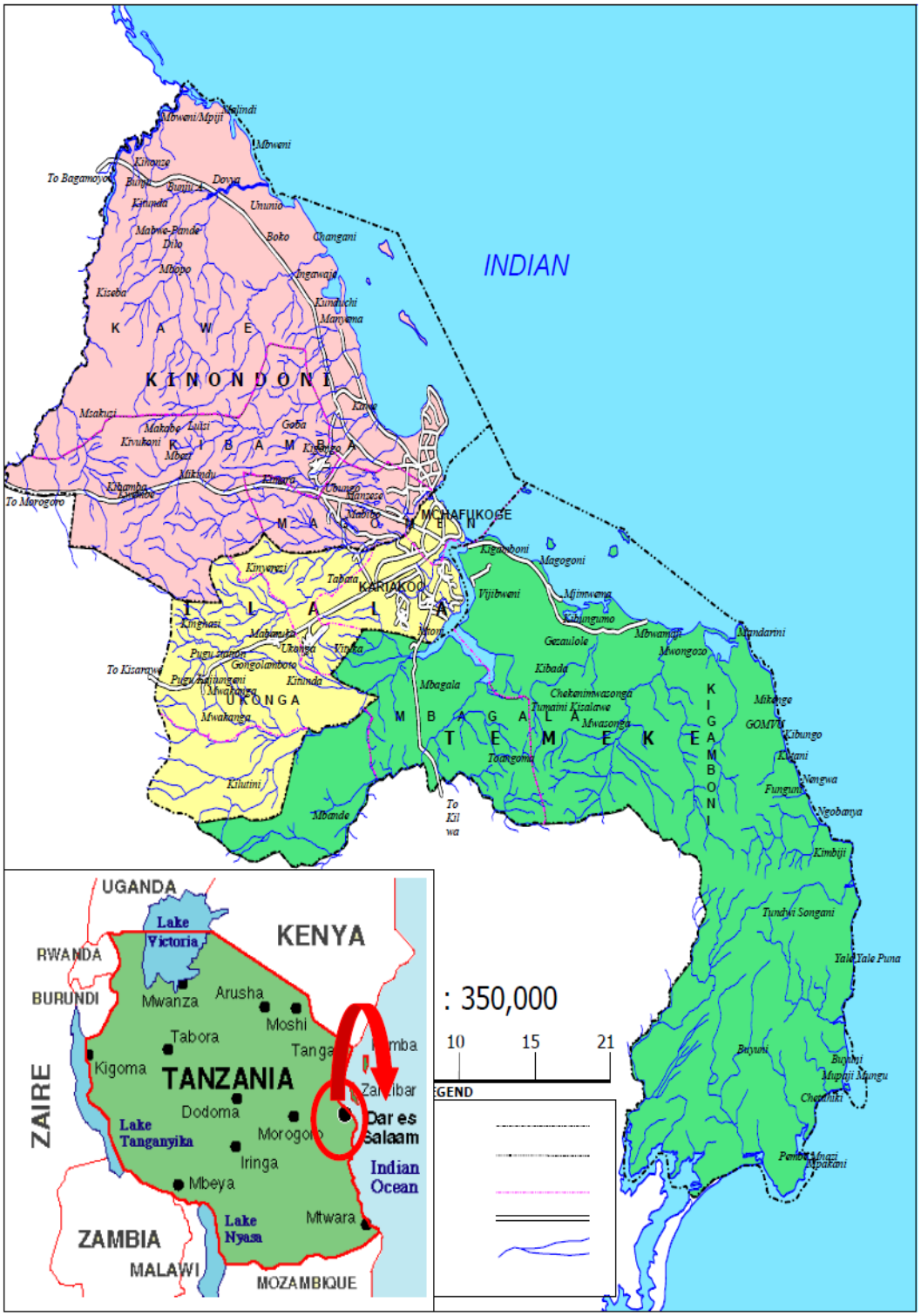


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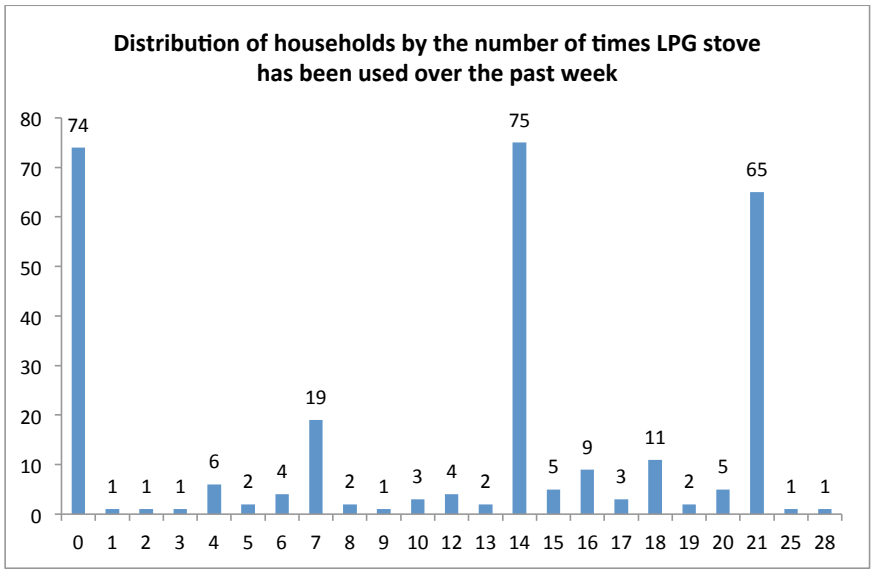
Figure A2



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