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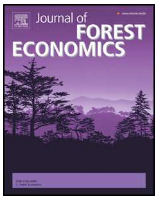

Rural households' participation in charcoal production in Zambia: Does agricultural productivity play a role?

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ABSTRACT

The study uses a nationally representative dataset of smallholder farmers in Zambia to determine the effect of agricultural productivity on households' participation in charcoal production. An instrumental variable probit approach is applied to account for the endogeneity of agricultural productivity in household's charcoal participation decision. We find a negative and significant effect of agricultural productivity on household's likelihood of participation in charcoal production. Results also show that higher education, income, asset value, and participation in off-farm employment opportunities reduce the likelihood of participation in charcoal production. Therefore, interventions seeking to reduce charcoal production in rural Zambia could benefit from improving smallholder agricultural productivity, incomes, asset base, and off-farm employment creation. However, interventions need not lose sight of other important macro-level factors.

Introduction

In Zambia like many other parts of sub-Saharan Africa (SSA), charcoal is one of the most important sources of energy for cooking and space heating among urban households. A comprehensive review of literature on charcoal and livelihoods in SSA by Zulu and Richardson (2013) indicates that about 80% of the urban population in the region relies on charcoal for cooking. Furthermore, a study by Tembo et al. (2015) on cooking fuel choice among urban households in Zambia finds 82% of urban households to be charcoal users. Demand for charcoal is likely to remain high in the foreseeable future, owing to the rising urban population, erratic electricity supply, high electricity tariffs, and few affordable alternatives. In addition most SSA countries are still struggling to formulate concrete policies promoting alternative energy sources.

On the supply side, almost all the charcoal is produced in rural areas but consumed in urban areas, with the majority of producers being smallholder farmers (Tembo et al., 2015; Kalinda et al., 2013; Mwitwa and Makano, 2012; Vinya et al., 2012). In fact, even if charcoal producers may not necessarily be farmers who produce enough for subsistence and/or sale, they usually have a small piece of land for food production within the home (Mulenga et al., 2014). Thus, charcoal is an important source of income for rural smallholder farmers, providing a steady flow of income for producers throughout the year (Mwitwa and Makano, 2012). However, charcoal has also been linked to a number of adverse environmental and health effects. These include localized deforestation and degradation, emission and inhalation of carbon monoxide during production. One of the longstanding debates regarding charcoal in SSA and Zambia in particular, is its effect on deforestation and forest degradation. In Zambia, charcoal has been identified as one of the main drivers of deforestation and degradation (Tembo et al., 2015; Government of the Republic of Zambia, 2014; Vinya et al., 2012). With the projected increase in charcoal demand and consequently production, there is need for analyses that would inform the design of interventions aimed at reducing charcoal production, without jeopardizing the livelihood of its producers. Given that majority of charcoal producers in Zambia are smallholder farmers, understanding the interaction between charcoal production and agricultural productivity is a useful input in designing such interventions.

A number of studies in Zambia and SSA identify low agricultural productivity and low agricultural income as being among the important household level supply side drivers of charcoal production (Arnold et al., 2006; Chidumayo, 2002; Mwitwa and Makano, 2012; Zulu and Richardson, 2013). These studies provide a foundation for understanding the linkages between agricultural productivity and participation in charcoal production. However,

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exploring this interaction is not the main focus of these studies. Furthermore, most of the existing studies in Zambia and SSA have relied on descriptive analysis, or small samples from selected regions of the country (e.g. Chidumayo, 2002; Mwitwa and Makano, 2012; Khundi et al., 2011). To the best of our knowledge, there are no empirical studies in Zambia or SSA that use a sample of national scope and control for potential endogeneity of agricultural, and much less quantify the effect of agricultural productivity on households' participation in charcoal production and/or sale.[1] An exception here could be Khundi et al. (2011) who model determinants of household participation in charcoal production and sale in Uganda by controlling for household level factors. However, their analysis does not directly address the question of whether agricultural productivity affects participation in charcoal production, but rather assesses the effect of agricultural capacity, measured in terms of agricultural tools owned by a household. Hence, very little is known in terms of the effect of agricultural productivity as a tool in helping address the rising charcoal production. Filling this knowledge gap is the main aim of this study.

Against this backdrop, the contribution of this study is twofold. First, the study is one of the first in sub-Saharan Africa to use nationally representative household level data to empirically and more directly address the question of whether agricultural productivity affects rural households' participation in charcoal production, as well as quantify this effect. Secondly, the study accounts for the potential endogeneity of agricultural productivity, thus providing more reliable estimates of the effects of agricultural productivity on households' participation in charcoal production. Most existing studies assume that agricultural productivity is exogenous to charcoal participation decision. However, this may not always hold due to the potential correlation between agricultural productivity and other unobserved factors that are also correlated with participation. The next section attempts to explain how and why agricultural productivity might be endogenous.

In this study agricultural productivity is measured using maize yield. We focus on maize because it is the dominant staple crop not only in Zambia, but also in sub-Saharan Africa, grown by the vast majority of households. In Zambia, maize has been a target of agricultural policies aimed at increasing agricultural productivity and food security in the country.

Charcoal participation decision and agricultural productivity

A few studies that attempt to relate agriculture and wood fuel production and/or sale assume that agricultural productivity is exogenous to the woodfuel participation decision (e.g., Fisher, 2004; Khundi et al., 2011; Mulenga et al., 2014). In reality, the assumption of exogeneity may not reflect how decisions are made. For example, it is not hard to see that increasing urban demand for charcoal coupled with rising charcoal prices creates incentives for smallholder households to participate in charcoal production, and in the long run would shift some of their labor and other resources toward charcoal production, hence reducing available resources for agricultural production. The result is a spurious correlation between participation in charcoal production and agricultural productivity. Furthermore, evidence show that localized deforestation around urban centers as a result of charcoal production, undermines production of ecosystem services, and agricultural productivity (Luoga et al., 2000; Arnold et al., 2006; Kambewa et al., 2007; Alem et al., 2010; Zulu and Richardson, 2013). The declining agricultural productivity would in turn compel farmers to participate in charcoal production in order to supplement agricultural incomes[2] (Mwitwa and Makano, 2012). Under such circumstances, agricultural productivity and participation in charcoal production are jointly determined, making it difficult to distinguish the effect of agricultural productivity on participation since participation in charcoal production may also affect agricultural productivity. The spurious correlation and joint determination of agricultural productivity and charcoal participation makes agricultural productivity potentially endogenous. Failure to control for endogeneity of agricultural productivity makes it difficult to distinguish the effect of agricultural productivity from confounding factors such as charcoal demand, and environmental degradation such as soil erosion.

Estimation procedure and identification strategy

Our empirical model is based on the standard probit regression model, where the dependent variable (household participation in charcoal/firewood production) takes on a value of one (1) if a household participated and zero otherwise. Two standard binary response models that are typically used are logit and probit. Linear probability model (LPM) which is fitted by ordinary least squares (OLS) is also used sometimes but it suffers some limitations which include: (i) the fitted probabilities can be less than zero or greater than one; and (ii) the partial effect of any explanatory variable is constant (Wooldridge, 2008). In standard binary outcome models, the conditional probability takes the form

$$Pr(y_i = 1|X) = F(X'_i\beta) \tag{1}$$

where Pr is the probability of the binary outcome y_i, which is dependent on a vector of exogenous explanatory variables X_i; βs are the unknown parameters to be estimated. The predicted probability falls between zero and one ($0 \leq Pr \leq 1$) and $F(\cdot)$ is a specified parametric function form for $X'_i\beta$. The two models (logit and probit) are similar except that they assume different functional forms. A logit model assumes a logistic distribution specified as $F(\cdot) = \Lambda(\cdot)$ while a probit model assumes a standard normal distribution specified as $F(\cdot) = \Phi(\cdot)$ (Wooldridge, 2008). Since both models are non-linear the estimated coefficients cannot be interpreted like linear models therefore partial effects are estimated. The two models are estimated using maximum likelihood estimation (MLE) given their non-linearity. For this study a probit model is chosen mainly because of its convenience in computing marginal effects. More specifically, our base empirical probit model is expressed as

$$\begin{aligned}\Pr(charc = 1) &= \beta_0 + \beta_1\ Gen + \beta_2 Age + \beta_3 Edu + \beta_4\ AdultsM \\ &+ \beta_5 AdultF + \beta_6\ Asset + \beta_7\ Inc + \beta_8 Incsq + \beta_9\ Land + \beta_{10}\ Yield \\ &+ \beta_{11}\ off - farm + \beta_{12}\ MktDis + \beta_{13}\ Prov + \varepsilon_i\end{aligned} \tag{2}$$

where the dependent variable (*charc*) is the household's decision whether to participate in charcoal production, taking the value of 1 if the household participated and 0 otherwise. Table 1 defines the explanatory variables used in the model.

However, a priori we expect maize yield to be correlated with the error term and participation, hence endogenous. Generally, the problem here is agricultural productivity could be correlated with some unobserved variables such as charcoal demand and soil degradation (which are captured in the error term), and these same unobserved variables could be influencing the participation decision. Hence, the effect of agricultural productivity on participation

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[1] We refer to charcoal production and/or sale as simply charcoal production, as almost all households that reported selling charcoal in our sample produced the charcoal.

[2] It is possible that farm incomes may fall due to declining maize prices and not productivity. However, we assume that maize prices are constant as most all the maize in Zambia is purchased by the government agency (Food Reserve Agency) at a nationally set price, usually higher than market prices.

Table 1
Variable description.

Variable	Variable definition
Charc	Household participation in charcoal production (=1 if yes)
Gen	Gender of the household head (1 = male, 0 = female)
Age	Age of the household head (years)
Edu	Education level of the head (years in school)
AdultM	Number of male adults members (15–59 years old)
AdultF	Number of female adult members (15–59 years old)
Asset	Value of asset (ZMW)
Inc	Gross income (ZMW)
Inc_sqd	Square of gross income
Land	Household land holding size (hectares)
Yield	Maize yield (kg/hectare)
Off_farm	Household participation in off-farm labor activities (=1 if yes)
Mkt_Dis	Distance to the nearest district center (kilometers)

is confounded by these factors leading to biased and inconsistent estimates (Wooldridge, 2010; Stock and Watson, 2003).

Following Newey (1987) we test[3] and control for potential endogeneity of agricultural productivity, by employing an instrumental variable probit (IV probit) model (Eq. (5)), which is basically a control function approach, despite its name (Baum et al., 2012). As our outcome variable (participation) is binary, and our suspected endogenous variable is continuous, a control function approach such as IV probit is more flexible and suitable compared to instrumental variable (IV) or 2 stage least squares (2sls) (Wooldridge, 2013). However, one critical challenge of the control function approach is finding at least one IV that is partially correlated with the endogenous variable being instrumented (relevance property), and should be uncorrelated with the error term (exogeneity property) (Stock and Watson, 2003). We instrument maize yield by the 2011 seasonal rainfall amount, basal and top dressing fertilizer application rates. Seasonal rainfall is a purely exogenous variable and highly correlated with maize yield, as almost all smallholder production is rain fed. Similarly, maize yield is highly influenced by how much fertilizer a farmer applies per unit area, but is less likely correlated with the participation decision. Furthermore, rainfall being a purely exogenous variable is independent of charcoal participation and the error term, and thus meets both requirements for a good IV. Theoretically, the use of rainfall, and fertilizer application rates as instruments appears to be a good choice, however, statistical tests are necessary to confirm this. Our statistical test, using *F*-statistics from the first stage regression was 221.94, much higher than the thresholds provided in Stock and Yogo (2005) of 23.63 for the reliability of *t*-tests based on IV estimates and for a sufficiently low probability that the bias of the IV point estimates is less than 5%. With such a high *F*-statistic, our choice of instruments is statistically valid, in addition to being theoretically logical.

Generally, our estimation procedure proceeds in two stages. The first stage estimates the maize yield function (reduced form model) by regressing maize yield on all exogenous explanatory variables to be used in the final participation model, plus the instruments. The first stage regression in our IV probit procedure can thus be represented by the equation

$$M_i = \alpha_i \boldsymbol{X_i} + \gamma_1 R_i + \gamma_2 B_i + \gamma_3 T_i + v_i \tag{3}$$

where M_i is the *i*th household maize yield, $\boldsymbol{X_i}$ is a vector of all exogenous explanatory variables, R_i is seasonal rainfall, B_i and T_i are respectively, basal and top dressing fertilizer application rates, α_i, γ_i are coefficients, and $v_i \sim N(0, \sigma_v^2)$ is the error term. We tested for multicollinearity in the model using variance inflation factor (VIF) (Kutner, 2004). The value of 10 served as a threshold to determine if multicollinearity was existed in a variable. All variables showed a VIF value of less than 10, indicative that multicollinearity was not a problem.

The second stage obtains predicted maize yield ($\hat{M}_i$) from (3), and include it as an explanatory variable in the second stage probit model in addition to all the exogenous explanatory variables ($\boldsymbol{X_i}$). The final participation IV probit is then formulated as;

$$y_i = a_i X_i + \delta_i \hat{M}_i + \varepsilon_i \tag{4}$$

where y_i is the participation variable taking a value of 1 if a household participated in charcoal production and 0 otherwise, the vector $\boldsymbol{X_i}$ is as defined above, α_i and δ_i are coefficients to be estimated, and $\varepsilon_i \sim N(0, \sigma_\varepsilon^2)$ is the error term.

Data

The study draws from a nationally representative household survey data of smallholder farmers in Zambia, the Rural Agricultural Livelihood Survey of 2012 (RALS12). The survey was conducted by the Indaba Agricultural Policy Research Institute (IAPRI) in collaboration with Central Statistical Office (CSO) and Ministry of Agricultural and Livestock (MAL) from June to July 2012. This survey covered the 2010/11 agricultural season, and the 2011/12 crop marketing year. The sampling frame of primary sampling units, or standard enumeration areas (SEAs),[4] was constructed using the results from the 2010 Census of Population and Housing. The SEAs were sorted by geographical codes to ensure that geographical distribution of the sample SEAs is also representative. The sampling frame included all rural SEAs, and a two-stage sampling scheme was adopted. At the first stage, SEAs in each district were selected using a probability proportional to size (PPS) procedure, with number of agricultural households a measure of size. A sample of 442 SEAs was drawn nationwide from a total of 12,789 SEAs from the sampling frame. The household was the second-stage sampling unit. Households were selected from each category using systematic random sampling, with a predetermined total of 20 sample households in each sample SEA, which resulted in a total sample size of 8840. However, due to one non-response, data were collected from 8839 households.

The RALS12 collected data from smallholder households in all 10 provinces of Zambia. Enumerators conducted face-to-face interviews using a semi-structured questionnaire to elicit household information on several aspects of rural livelihood, including socioeconomic, demographic characteristics, production activities and income sources. Further, the RALS12 also collected data on natural resources access and utilization, input and output market access. On charcoal, the RALS12 collected data on whether any member of a household participated in charcoal production and/or sale in the last 12 months prior to the survey. Although the question asked about member participation, the variable participation is at household level, since if any member of a household participated in charcoal production, then such a household was reported as a participant. The RALS12 dataset thus allows for econometric estimation of determinants of household participation in charcoal production, as well as descriptive analysis to compare socioeconomic characteristics of charcoal production participants and their non-participating counterparts.

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[3] A Wald test of the exogeneity of the instrumented variable is automatically provided with the IV probit estimation. We reject the null hypothesis of no endogeneity if the Wald statistic is significant. However, if the test statistic is not significant, there is not sufficient information in the sample to reject the null, hence a regular probit regression may be appropriate.

[4] A standard enumeration area (SEA) is the smallest administrative unit for data collection purposes in Zambia. On average, each SEA has a population of between 80 and 120 households.

Table 2
Sample characteristics of charcoal participants and non-participants.

Attribute	Whole sample	Participants	Non-participants	Significance
Demographics of head				
Age of the head (years)	45.63	41.72	45.79	**
Gender of head (1 = male)	0.83	0.92	0.82	**
Education of the head	6.3	6.12	6.3	**
Production and productivity				
Maize yield (kg/ha)	2352	2146	2360	**
Total maize production (kg)	3672	1845	3744	**
Land ownership and acquisition				
Total land cultivated (ha)	2.58	1.84	2.61	*
Total land holding (ha)	4.11	3.21	4.15	**
Wealth				
Value of assets (ZMW)	17,060	5856	17,504	*
Market participation				
Distance to the market (km)	11.27	7.07	11.44	*

Source: Authors' calculations from Rural Agricultural Livelihood Survey (2012).

* $p < 0.05$.

** $p < 0.01$.

We also used dekad (10-day period) spatial rainfall data from the Climate Hazards Group Infrared Precipitation with Station database (CHIRPS). CHIRPS is a quasi-global spatial database (50’S to 50′N) with a resolution of 0.05′ (Funk et al., 2014). Seasonal rainfall for the 2010/2011 season was calculated from dekad-level rainfall variables and then merged with household data at the standard enumeration area level.

Results and discussion

Descriptive results

Table 2 presents a summary of the descriptive analysis, comparing charcoal producing households (participants) and non-charcoal producing households (non-participants). The results show significant variations for a number of variables across the two groups. Consistent with, Khundi et al. (2011), results indicate that households participating in charcoal production had relatively younger heads, with an average age of 41.7 years, compared to their non-participant counterparts whose head on average was 45.8 years old. This is perhaps due to the fact that charcoal production involves heavy drudgery that older heads may not be able to perform. In addition, proportionately more participant households were headed by males than non-participants. It appears therefore, that charcoal production is predominantly practiced by households headed by younger heads, mostly male. Household size showed significant variation between the two groups, with the non-participant households having an average of 6 household members compared with 5 members for participants.

In terms of the value of assets owned (a proxy for wealth), our analysis revealed that households that participated in charcoal production had significantly less valuable assets (ZMW 5856[5]) compared to that of non-participants (ZMW 17,504). This corresponds with findings by other studies in SSA (e.g., Arnold et al., 2006; Khundi et al., 2011; Zulu and Richardson, 2013) indicating that most households that participate in charcoal production are poorer. Furthermore, there was a statistically significant difference between the incomes of participants and non-participants, with the latter having higher incomes, consistent with Khundi et al. (2011). Mulenga et al. (2014) found that wealthier households derived income from a variety of formal and informal businesses other than charcoal, while poor households relied on charcoal for a greater share of their income. This is due to the low entry barriers in charcoal production such as no formal education and low capital investment (Chidumayo, 2002). Furthermore, this could perhaps be an indication that availability of off-farm opportunities help reduce likelihood of participation in charcoal production.

Regarding maize production, participants had relatively low maize productivity (2146 kg/ha) compared to their non-participant counterparts (2360 kg/ha). Total cultivated land showed significant variation between the two groups, with the non-participants having cultivated more land (2.6 ha) than participants (1.8 ha). This is consistent with Mweemba and Hongjuan (2008). The majority of rural Zambian households engaged in agriculture cultivate less than a hectare of land on average (Hichaambwa and Jayne, 2012). Households with fewer members tend to focus more on agricultural production as it provides a sustainable and steady source of income. However, no significant difference was observed between the two groups regarding total landholding size.

In terms of distance from the homestead to the nearest district center (proxy for market access), results indicate that participants were, on average, located about 7 km from the market compared to non-participants, whose homestead was located about 11 km from the market, and this difference was statistically significant. It seems therefore that proximity to markets creates incentives to produce engage in charcoal production (Table 2).

Further analysis was conducted to examine the relationship between maize yield and the likelihood of participation in charcoal production (Table 3). We divided the sample of maize producing households into four approximately equal sub-groups (quartiles) based on maize yield. We then calculated the percentage of households participating in charcoal production within each of the quartiles. From this analysis a pattern emerged, suggesting that there are proportionately more households participating in charcoal production among households with low yield and fewer among those with relatively higher yields. This perhaps shows the negative relationship between maize productivity and likelihood of participation in charcoal production. An analysis of variance (ANOVA) testing differences in percentage of households participating in charcoal across maize yield quartiles indicate that the observed participation percentages were statistically significant. However, it is difficult to deduce causality based on descriptive analysis and test of mean differences since we are not controlling for other factors. In order to determine causality, we used econometric analysis, whose results we present and discuss next.

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[5] As at July 2012 when the data was collected, USD 1 was equivalent to ZMW 5.7.

Table 3
Maize yield quartiles and percent of households participating in charcoal production.

Statistic/maize yield quartiles	Maize yield quartiles			
	First quartile (1944)	Second quartile (1951)	Third quartile (1954)	Fourth quartile (1925)
Average maize yield (kg/ha)	611.0279	1462.714	2436.974	4554.654
HH producing charcoal	6.1%	5.6%	4.9%	4.5%

Source: Authors' calculations from Rural Agricultural Livelihood Survey (2012).

Econometric results

Table 4 presents IV probit estimates of factors that help explain household participation in charcoal production. Column 1 presents results of the reduced-form OLS analysis of maize yield, while column 2 and 3 are second-stage IV probit coefficients and marginal effects (evaluated at the means), respectively. Generally, high household income, asset value, rainfall and top dressing fertilizer application rate lead to increased maize yield. In regards to participation, we focus on the marginal effects, which represent the change in participation likelihood resulting from a change in the explanatory variable, holding all other variables at their means. Wald test of exogeneity was conducted and results indicate sufficient evidence of endogeneity (p-value = 0.002), confirming our earlier suspicions that agricultural productivity is endogenous and reinforcing our use of IV probit to address the endogeneity problem. Generally, results indicate that participation is partly explained by household demographic factors, asset value, income, market access, and agricultural productivity. In terms of demographics, participants are likely to be headed by young, less educated males. The negative effect of age of household head on participation is possibly due to the fact that charcoal production and marketing is labor intensive and therefore less attractive to the older population. The gender effect indicates male-headed households to be about 2.8 percentage points more likely than their female-headed counterparts to participate in charcoal production. This result corresponds with most literature (e.g. Chidumayo, 2002; Shackleton and Shackleton, 2006), and further confirms the widely held assertion that charcoal production is a predominantly a male activity. While this might hold for charcoal, it may not necessarily be true for firewood collection, which is mostly a female activity. However, over 98 percent of the reported wood fuel sales in our sample were from charcoal. The negative effect of education on participation is perhaps due to the fact that education expands the possibilities for labor and employment, and hence helps reduce households' likelihood of participation and reliance on forest resources, con-

Table 4
OLS maize yield and IV probit estimates for participation in charcoal production.

Explanatory variable	OLS (maize yield)	Participation (=1 if yes)	
		Coefficient	Marginal effect
Maize yield (kg/ha)		−0.363	−0.037
		(0.103)**	(0.013)**
Age of the head	0.000	−0.008	−0.001
	(0.001)	(0.002)**	(0.000)**
Gender of the head (=1 if male)	−0.033	0.266	0.027
	(0.022)	(0.092)**	(0.009)**
Education of the head	−0.001	−0.025	−0.003
	(0.002)	(0.008)**	(0.001)**
Number of male adult members	−0.016	−0.012	−0.001
	(0.008)	(0.030)	(0.003)
Number of female adult members	−0.016	−0.014	−0.001
	(0.009)	(0.032)	(0.003)
Log of gross income (ZMW)	0.753	3.360	0.346
	(0.084)**	(0.722)**	(0.078)**
Square of log of gross income	−0.018	−0.098	−0.010
	(0.003)**	(0.022)**	(0.002)**
Value of assets (ZMW)	0.014	−0.101	−0.010
	(0.006)**	(0.023)**	(0.002)**
Landholding size (ha)	−0.001	−0.020	−0.002
	(0.001)	(0.009)*	(0.001)*
Distance to nearest district center	0.005	−0.027	−0.003
	(0.001)	(0.007)**	(0.001)**
Off-farm labor participation (=1 if yes)	−0.124	−0.269	−0.027
	(0.019)**	(0.070)**	(0.007)**
Log of seasonal rainfall	46.498		
	(5.827)**		
Square of seasonal rainfall	−3.462		
	(0.434)**		
Basal fertilizer application rate (kg/ha)	0.000		
	(0.000)		
Top dressing fertilizer application rate (kg/ha)	0.003		
	(0.000)**		
Joint provincial dummy test	51.44**	110.1**	
R squared	0.38		
Wald exogeneity test statistic			6.12**
Number of observations	7579	7579	7579

Note: Values in parenthesis are robust standard errors; we included 9 provincial dummy variables, although not shown in the table.

[*] $p < 0.05$.

[**] $p < 0.01$.

sistent with other studies (e.g., Dolisca et al., 2007; Fisher et al., 2010; Khundi et al., 2011).

In regards to assets and income, participants are likely to have less valuable assets (including livestock), but relatively higher incomes. However, likelihood of participation increases at a decreasing rate with rising incomes (as shown by a negative squared income term), implying that initially as incomes increase, participation also increases but further increases in income would reduce participation likelihood. This plausibly implies that participant would produce charcoal to supplement household income, but only up to a certain point, before the likelihood of participation declines. It appears therefore that charcoal producers are not necessarily the poor of the poorest, at least in Zambia. Similar with Khundi et al. (2011) it is seemingly evident that charcoal producers do not have high enough incomes to invest in assets, as indicated by the low asset values relative to their non-participant counterparts.

In terms of market access, a number of studies have relied on distance to the nearest district center as a measure of market access (e.g., Abdulai and Huffman, 2014; Ngoma et al., 2016). Similarly, we use distance to the nearest district center as a proxy for market access, and we find market access to significantly reduce the likelihood of participation. This perhaps is due to the high transport costs and consequently low charcoal profit margins associated with distant markets (Malimbwi et al., 2005). Thus, households that have better access to markets are more likely to participate in charcoal production and sale as a source of income. This phenomenon is well documented in Zulu and Richardson (2013), who note the important role of charcoal as an income source among rural households that have access to markets.

Turning to the main question of whether agricultural productivity helps explain charcoal participation, results reveal that it does. As stated in the earlier sections, a number of studies have claimed that agricultural productivity affects participation in charcoal production, but most of these are descriptive or simply narrative, and hence unable to indicate by how much participation is likely to change due to changes in productivity. Our estimates show that all else equal, an increase in maize yield of 10 kg/ha, for an average household in our sample, would reduce a household's participation likelihood by almost 37 percentage points. Khundi et al. (2011) find a 4.7 percentage points reduction in participation likelihood for one Ugandan shilling increase in value of agricultural tools owned by a household. Although measuring different aspects of productivity, our results and those from Khundi et al. point to agricultural productivity being an important factor in explaining participation. However, other extenuating factors not well captured by our model such as increasing urban demand for charcoal, increasing urban population, and lack of alternative livelihood options are important. Thus interventions aimed at reducing charcoal production by smallholder households need a more comprehensive approach.

Furthermore, results show that landholding size influences participation, with participants owning relatively less land than their non-participant cohorts. Although Zambia appears to have abundant land, the country is experiencing a paradox of land scarcity in the midst of plenty, mainly created by a settlement pattern where most rural households want to settle in areas that are close to infrastructure, social amenities, markets, etc. Hence there is a concentration of settlements in these areas rendering land in these areas scarce. This paradox is well-documented in a study by Hichaambwa and Jayne (2012). Opening up more settlements by investing in infrastructure and social amenities, flanked by, among other things, improved technological adoption and input accessibility could help boost smallholder agricultural expansion, and help reduce pressure on forest resources. Our results also show that participation in off-farm labor activities help explain participation. It appears therefore that availability of off-farm employment opportunities could help reduce households' charcoal participation likelihood. This finding is consistent with others (e.g., Angelsen and Kaimowitz, 1999; Chidumayo, 2002; Mulley and Unruh, 2004; Zulu and Richardson, 2013).

The lack of nationally representative data on the distribution and availability of wood resources presented a limitation of this study, as we were unable to effectively account for spatial variability. To partially address this issue, provincial dummy variables were used to account for spatial that may exist across provinces. A joint *F*-test of the provincial dummy variables was significant, indicative that spatial variability helps explain participation. Further, we clustered error terms around (SEAs), as this smaller spatial unit (SEA) is likely to be more able to account for characteristics common to households in the same area but different from those of other areas, such as wood resources distribution and availability.

Conclusions

This study used a nationally representative dataset of smallholder farmers and employed econometric analysis, accounting for endogeneity to estimate the effects of agricultural productivity on rural households' participation in charcoal production in Zambia. Generally, our findings indicate declining likelihood of participation with increasing agricultural productivity, and increases in socioeconomic variables such as education, asset holding, land ownership and income. Our analysis is among the first to quantify the effect of agricultural productivity on household charcoal participation in sub-Saharan Africa. We estimate that a unit increase in maize yield would reduce participation likelihood by over 3.7 percentage points. Our finding of a large effect of agricultural productivity on charcoal participation suggests that agricultural productivity should continue being an integral part of efforts aimed at curbing the rising charcoal production and associated environmental degradation. Results also underscore the importance of alternative livelihood options, such as off-farm employment opportunities, in reducing charcoal participation likelihood. However, such interventions need not lose sight of other macro-level factors such as rising urban population and charcoal demand. Therefore, curbing the rising charcoal production requires a more comprehensive and coordinated approach across different sectors in order to design effective interventions.

Looking beyond this study, future research should consider controlling for distribution and availability of forest resources in a much more direct manner, since access to forest resources plays an important role in influencing livelihood options. Also, the use of panel dataset would help in understanding whether rural households only use charcoal to supplement agricultural incomes, or whether the activity is increasingly becoming the mainstay.

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