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Biofuels and rural livelihoods: Empirical evidence on the welfare impacts of Jatropha cultivation in southern Malawi

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Abstract

This study evaluates the welfare impacts of jatropha (*Jatropha curcas*) cultivation measured as consumption expenditure per adult-equivalent for smallholders in southern Malawi. Household survey data from the southern region of Malawi collected in 2014 from 303 smallholders using purposive and random selection strategies were used. Propensity score matching and endogenous switching regression methods were employed to address the selection bias problem and to control for observed and unobserved covariate effects. The analysis suggests that when selection bias and endogeneity were accounted for, jatropha cultivating farmers' welfare was lower as compared to their counterparts. In the absence of tangible empirical evidence on welfare benefits to smallholder jatropha feedstock producers, this study concludes that jatropha is unlikely to bring meaningful welfare benefits to smallholders. As such, further research should consider pursuing other potential biofuel options like 'moringa' for biodiesel in the future Malawi biofuels policy. These findings also show that biofuels are not a panacea to the rural development and welfare of smallholders. Rather, the results suggest that programme initiatives which build household assets need to be encouraged to improve the plight of rural households largely dependent on agriculture.

Keywords: Jatropha, welfare impact, propensity score matching, endogenous switching regression, southern Malawi

1 Introduction

1.1 Background

Agriculture plays a significant role in the economy of Malawi. It contributes up to a third of the country's gross domestic product and employs over 60 % of the total labour force (Government of Malawi, 2013; NSO, 2014). Arable crop farming is a primary source of livelihoods, complemented by livestock rearing in most rural areas of the country. The majority of the population (86 %) is rural-based (NSO, 2012; 2014).

Biofuel feedstock production is an agricultural activity. The recent prominence of biofuels internationally and in sub-Saharan Africa (SSA) has been attributed in the literature to crude oil price volatility and national energy security, new market opportunities, climate change mitigation, foreign exchange savings, and the potential to transform the rural economy (Jumbe *et al.*, 2009; Mudombi *et al.*, 2016).

Malawi has consistently blended fossil fuel with bioethanol from sugarcane molasses since the 1980s while biodiesel blending followed only recently. The extensive cultivation of jatropha as a high-value tree crop for biofuels production only gained momentum much later (early 2000s). *Jatropha curcas*[1] is one of the biofuel crops that gained prominence due to its many attributes such as: (i) its low management requirements, (ii) adaptability to marginal lands, and (iii) the fact that it is not a food crop. These attributes led to the creation of ambitious targets in developing countries to attract foreign investors. Most governments in SSA have existing or proposed biofuel blending mandates of up to 10 % (Jumbe *et al.*, 2009; Jumbe & Mkondiwa, 2012; Gasparatos *et al.*, 2015). At the peak of the jatropha hype in the early 2000s, SSA was estimated to have contributed 13 %

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[1] *Jatropha curcas* is a tropical oil-seed tree crop which grows well in low altitude areas (0 to 500 m) and tolerates moderate annual rainfall conditions (300 to 1,000 mm). The seeds have a high oil content which can be extracted and used as a straight vegetable oil or blended with fossil fuel (paraffin or diesel) to make biofuels (Achten *et al.*, 2008; Makungwa *et al.*, 2013).

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to the total global land under jatropha cultivation (Brittaine & Lutaladio, 2010; Kant & Wu, 2011).

Smallholders' participation in the biofuels value chain is in feedstock production as wage earners (industrial plantation) or as out-growers selling jatropha seeds (Achten *et al.*, 2008; Achten *et al.*, 2010). Jatropha can be cultivated as a monocrop (as in plantations) or as hedgerows around farmsteads and homes. Traditional uses of jatropha never warranted application of scientific knowledge to improve the economic importance of the crop; to a considerable extent, it has been promoted as a developmental crop with untapped potential (Brittaine & Lutaladio, 2010). In Malawi, Bioenergy Resources Limited (BERL), a private company, was one of the prominent stakeholders which invested resources (extension materials and staff) to promote jatropha cultivation. Smallholders in the targeted areas were encouraged to grow jatropha in hedgerows around boundaries of their fields and on marginal lands for biofuels production, amidst concerns of potential conflict with food security (Mponela *et al.*, 2011; von Maltitz *et al.*, 2014).

Arguments surrounding negative externalities caused by biofuels promotion, which include land tenure security, indirect land use change and food security concerns, remain extensively debated issues (Ajanovic, 2011; Mwakaje, 2012; Pradhan & Mbohwa, 2014). Nevertheless, others argue that a delicate balance exists within certain thresholds that limits the carbon debt depending on types of feedstock and production practices used (Romeu-Dalmau *et al.*, 2016; Schuenemann *et al.*, 2016). Despite the collapse of many previous biofuel projects across Africa (mostly industrial plantations), a few jatropha projects survived like the case of some plantations in Mozambique and out-grower schemes in Malawi (Gasparatos *et al.*, 2012; von Maltitz *et al.*, 2014; von Maltitz *et al.*, 2016).

In Malawi, rural livelihoods mostly depend on traditional cereal crops like maize (staple food), legumes such as beans and groundnuts, and limited cash crops such as tobacco, cotton and tea depending on agroecological zones. The growing of jatropha as a feedstock by smallholders in the targeted areas contributes to crop diversification in the enterprise mix (Nalivata & Maonga, 2011; Government of Malawi, 2013).

1.2 Rationale of the study

A few studies exist on biofuels in Malawi. Previous jatropha research has focused on areas like policy, awareness, small-scale processing, adoption, and socioeconomic impacts among others (e.g. Jumbe *et al.*, 2009; Mponela *et al.*, 2011; Nalivata & Maonga, 2011; von Maltitz *et al.*, 2014; Gasparatos *et al.*, 2015; Mudombi *et al.*, 2016; von Maltitz *et al.*, 2016). The literature on socioeconomic impacts of biofuels cultivation at the local level has largely remained theoretical, qualitative, and has not addressed sample selection bias (Hodbod & Tomei, 2013; Mudombi *et al.*, 2016). Farmers can self-select or stakeholders target interventions to specific areas potentially causing selection bias. A quantitative study on the impact of jatropha cultivation on smallholders' livelihoods that addresses sample selection bias in Malawi has not previously been conducted. Failure to account for selection bias in the estimation of outcomes might lead to under- or over- estimation of the effects of biofuels promotion at the local level. With the publicity of the promise of biofuels to deliver on the rural development agenda, this empirical study is well justified (Ewing & Msangi, 2009; Ambali *et al.*, 2011; Herrmann *et al.*, 2017).

The current study aimed to provide empirical evidence and rigorous quantitative analysis of the impact of jatropha cultivation for biofuels production on smallholders' welfare in the Mangochi district of southern Malawi. More specifically, the study evaluated the poverty profiles of smallholders cultivating jatropha. Secondly, the study investigated the determinants of smallholder welfare at the local level, measured as consumption expenditure per adult equivalent unit (AEU). Lastly, the study evaluated the welfare impact of jatropha cultivation on smallholders.

The current study differs from an earlier study (Mudombi *et al.*, 2016) in various ways. Firstly, the current study applied rigorous econometric techniques that account for sources of selectivity bias caused by non-randomness in the identification of smallholders cultivating jatropha. Secondly, this study used consumption expenditure per AEU as a measure of household welfare widely used in welfare studies (Asmah, 2011; Sinyolo *et al.*, 2014). Consumption expenditure per AEU was chosen as a suitable indicator for such investments that are relatively new compared to the multidimensional approach (adopted by Mudombi *et al.*, 2016) which uses semi-durables (assets). The choice of consumption expenditure over income draws from well-documented merits of its reliability and relative ease in capturing the data (Deaton, 1997).

2 Methodology

2.1 Data and study area

The study was conducted in the Mangochi district of Malawi, one of the few areas in southern Africa where smallholder out-grower jatropha schemes were still operational (von Maltitz *et al.*, 2016). The Mangochi district is under the Machinga Agriculture Development Division (ADD) of the Ministry of Agriculture. This area was selected following a reconnaissance survey which traced sources of the bulk of jatropha seeds delivered to BERL in 2014. Several consultations were also conducted prior to the study, with relevant stakeholders in the biofuels value chain in Malawi (Buyers – BERL, intermediaries, and Ministry of Agriculture staff) to assist in identifying the study site.

The primary data used in this analysis were collected using purposive and random sampling strategies at the different stages of the sampling. Smallholders cultivating jatropha were purposively selected from BERL investment areas, where they promoted jatropha cultivation (treatment sample). The counterfactual households (untreated group) were randomly drawn from similar neighbouring Extension Planning Areas (EPAs[2]), where BERL did not promote jatropha cultivation. Four EPAs were selected for study with the help of the Mangochi district agriculture staff, two for jatropha cultivating farmers (Nankumba and Lingwena EPAs) and two for the non-jatropha growers (Maiwa and M'bwadzulu EPAs).

A structured household questionnaire, which was pretested in Cholwe EPA (in Lilongwe Agriculture Development Division), was used to capture agricultural practices, outputs, household demographics and socioeconomic information relevant to the study. Key informant and focus group discussion checklists were used to collect additional information to complement the structured questionnaire. Hired enumerators were trained and familiarised with the data collection instruments before administering them. A total sample of 303 farmers was interviewed. The sample comprised of 100 jatropha cultivating farmers (hereafter JCFs), and for every JCF interviewed, two non-jatropha farmers (hereafter NJFs) were also interviewed to increase chances for identification of counterfactuals in the latter part of the analysis. Key informant interviews[3] and two community focus group discussions were conducted, one for JCFs and another for the NJFs.

2.2 *Empirical strategy*

Sen (1981) entitlement thesis pioneered poverty classification to map vulnerability. Poverty of a household can be assessed as an outcome of their capability, functioning, access to important infrastructure and services used to earn a living. Absolute poverty captures the headcount of households unable to meet defined basic bundles of goods and services. Relative poverty measures the gap in income to meet defined minimum welfare thresholds (e.g. poverty line). The Foster Greer Thorbecke (FGT) approach, which decomposes poverty into (i) incidence, (ii) gap, and (iii) severity of poverty, was used to compare poverty profiles between JCFs and NJFs. The FGT index is a commonly used technique in poverty assessments merited for its simplicity and decomposability (NSO, 2012; Sinyolo *et al.*, 2014). The FGT indices were calculated using Stata 15.

This study aimed at estimating the welfare impacts of jatropha cultivation through a causal relation. The lack of randomization in placement of treatment units causes selection bias and the decision to participate in jatropha cultivation can be potentially endogenous. To account for endogeneity and self-selection bias, the study used two complementary techniques, the endogenous switching regression (ESR) and propensity score matching (PSM), which use counterfactual scenarios.

The rationale behind PSM is to construct a statistical group of counterfactuals likely to participate in an intervention using observable characteristics. The technique uses binary regression to generate propensity scores on pretreatment observable characteristics likely to influence participation. The propensity scores are used to identify observationally similar non-participants to match with the participant. Treatment effect is given by the difference in outcomes of interest between treated and counterfactual observations. The conditional independence assumption (CIA) assumes treatment does not affect outcomes, meaning that there are no unobserved factors affecting outcomes (Khandker *et al.*, 2010). Accordingly, the balancing property was employed to improve the quality of matches following several iterations. Block adjustments were made, and the common support condition was also imposed. The rationale was to ensure sufficient overlap and even distribution of observations within blocks between treament and untreated units. The model was estimated using two different algorithms, propensity score matching (PSM) and nearest neighbour (NN) method to test consistency of the results in Stata 15.

The ESR model accounts for selection bias and structural differences between the outcome functions of jatropha cultivating farmers and the non-jatropha farmers. The ESR allows for covariate effects to vary across the two outcome functions and shows the extent of covariate influence. The model specification can be presented in two parts; the first part represents a binary choice H_i^* whether to cultivate jatropha or not based on expected net benefits. The second part represents the dependent continuous function which models outcomes. Using notations, let a farmer belonging to regime 1 (JCFs) or regime 2 (NJFs) be denoted by a binary latent variable H_i^*, taking the value of 1 when observed and 0 otherwise. The observable variable H_i for

[2]EPAs are the lowest administrative structures in the agriculture extension system of the Ministry of Agriculture in Malawi.

[3]One chief's councillor and three agricultural extension development coordinators (AEDC) were interviewed covering all the four Extension Planning Areas where the study was conducted.

latent variable H_i^* belongs to the regime 1 (JCFs) or regime 2 (NJFs) in the following form:

$$H_i^* = \alpha Z_i + \omega_i \text{ where } H_i = \begin{cases} 1 & \text{if } H_i{>}0 \\ 0 & \text{if } H_i{\leq}0 \end{cases} \quad (1)$$

$$y_{1i} = X_i\beta_1 + \mu_1 \text{ (JCFs equation)} \quad \text{if } H_i = 1 \quad (2)$$

$$y_{2i} = X_i\beta_2 + v_1 \text{ (NJFs equation)} \quad \text{if } H_i = 0 \quad (3)$$

where y_{ji} are welfare functions (dependent variables). In this study, household welfare was defined as both marketable and non-marketable goods and services that the household consumes. The proxy used to measure household welfare was household consumption expenditure normalised by the square root of household size to allow for scale economies (Deaton, 1997; van de Walle, 2013). X_i and Z_i are vectors of regressors, and α, β_1, β_2 are vector parameter estimates. The variables ω_i, μ_i, and v_i are error terms assumed to have a trivariate normal distribution with mean zero and covariance matrix Ω. The full information maximum likelihood (FIML) approach efficiently estimates the binary choice and continuous outcome equations simultaneously (Maddala, 1983; Lokshin & Sajaia, 2004). The movestay command written by Lokshin & Sajaia (2004) was used to run the model in Stata 15.

The impact of jatropha cultivation on household welfare can be calculated by comparing the observed outcome y_{1i}, with the counterfactual outcome y_{2i}, to capture the overall benefit of jatropha cultivation (Maddala, 1983). The expected outcomes were also used to calculate the base heterogeneity effect. Base heterogeneity captures unobservable characteristics (e.g. attitude to work, entrepreneurial spirit), which can separate JCFs from NJFs even before adopting the crop (Di Falco *et al.*, 2011).

To test robustness of the results, selection bias was also modelled as a function of observable characteristics. PSM uses the probability of participating in an intervention using observable characteristics to construct a counterfactual group for comparison of outcomes. Propensity scores generated from probit or logit models are used to match intervention households with the untreated units. The mean difference in outcomes between intervention units or JCFs (denoted $Y_{1i} = 1$) and 'similar' untreated group or NJFs (denoted $Y_{2i} = 0$) is the estimated average treatment effect on the treated ($Y_{1i} - Y_{2i}$) (Wooldridge, 2002).

The major limitation of this study is that the analysis used a cross-sectional dataset. As such, it does not provide the temporal dimension which can better be observed using panel data to track changes in welfare of the observed households over time.

3 Results

3.1 Descriptive statistics

Table 1 presents basic summary statistics of smallholders on household demographics and other socioeconomic characteristics. The average age for the smallholders was 45.6 years and most households were male-headed. The average land holdings size was 1.3 hectares. Key informant interviews revealed that most of the land in the study areas falls under customary land tenure and ownership was passed on through a matrilineal inheritance system. Farming was a primary occupation like in most rural areas in the country though some significant differences were observed between JCFs (87 %) and NJFs (93 %). In places where jatropha was cultivated, the fishing value-chain was ranked as the most important livelihood strategy. However, the distribution of the proceeds from fishing activities were inclined to favour male-headed households (72 %) as gender participation and roles showed that most of the activities (primary fishing, pulling nets, rope making) were male dominated except for small scale fish trading which was ranked as least important (see Appendix 1: Supplementary material). Conversely, NJFs considered farming (rainfed agriculture) and winter season wetland cultivation as their most important livelihood strategies. The household asset index showed that JCFs had significantly fewer durable assets compared to NJFs. Similarly, JCFs had significantly less access to agriculture equipment compared to NJFs. However, jatropha cultivating farmers owned significantly more livestock, measured in tropical livestock units[4] (1.5), compared to NJFs (0.47).

Regarding access to public facilities and other services, there were large variations in reported access to extension and nearest trading centres. While slightly over half of the JCFs (55 %) had access to extension services, a significantly large number of NJFs (77 %) had contacted an agricultural extension agent in the year of the study. Public phones were used as proxies for remoteness of the area. JCFs were significantly further away from trading centres where households could access important services such as input and output markets.

Jatropha cultivating farmers received significantly less income from crop sales by an average of almost 60 % compared to NJFs. Discussions with farmers described the following as constraints to agricultural production: unaffordable prices of inorganic fertilisers, challenges in accessing government subsidized fertiliser, climate variability,

[4]Tropical livestock units (TLUs) is a widely used index for livestock owned which is based on body weight regardless of species compared to a unit reference of a 250 kg animal

Table 1: *Means of household descriptive and socioeconomic variables for jatropha cultivating farmers (JCFs) and non-jathropha cultivating farmers (NJFs) (n = 298).*

Variables	*All Sample*	*JCFs (n=96)*	*NJFs (n=202)*	*t-test (chi^2)*
Household demographics				
Age (years)	45.6	47.7	44.6	1.61
Gender of HH head (1 = male)	0.72	0.74	0.71	0.23
Household size	5.87	5.85	5.88	0.12
Household size in adult equivalents*	4.3	4.4	4.2	0.9
Effective household labour† (adjusted man-equivalent units)	2.49	2.49	2.49	0.029
Primary occupation (1 = farmer)	0.91	0.87	0.93	3.40*
Farming experience (years)	27	28.2	26.4	0.98
Mean household education endowment‡	3.8	3.6	3.9	1.5
Access to off-farm income (1 = Yes)	0.51	0.53	0.5	0.25
Household wealth and farm variables				
Landholding size (ha)	1.3	1.3	1.4	0.4
Soil fertility status (1= fertile)	0.27	0.29	0.26	0.39
Tropical Livestock Units	0.81	1.5	0.47	2.82**
Household Asset index§	0.0013	-0.29	0.14	2.48*
Agric. equipment access index¶	0.0005	-0.32	0.15	2.79**
Output and Outcome variables				
Consumption expenditure/AEU (,000 Mwk)‖	90.3	80	95.3	2.73**
Crop sales income (,000 Mwk)	46.6	32.5	53.3	1.9*
Livestock sales income (,000 Mwk)	11.7	13.3	11.1	0.66
Off-farm income (,000 Mwk)	88.8	71.4	97.1	1.28
Level of food production (1= enough)	0.33	0.24	0.37	5.11*
Access to services and amenities				
Public phone (distance in minutes)	11.3	13.8	10.0	2.45*
Extension access (1 = Yes)	0.7	0.55	0.77	14.3***
Credit access (1 = Yes)	0.31	0.27	0.33	1.1

*Household size was adjusted for age and gender (Ligon & Schechter, 2003).

†Effective household labour availability in man-equivalent units was calculated as follows : children < 9 years = 0, 9 to 15 years = 0.7, 16 to 49 years =1 and > 49= 0.7 (Runge-Metzger, 1988 cited in Kuntashula & Mungatana, 2013). Due to data availability, these units were further modified to account for the working status on the farm for all family members as follows: full time = 1 and part-time = 0.5.

‡Education endowment was calculated as the average number of years of schooling for all household members.

§The household asset index was constructed using principal component analysis. All household assets were first categorised as dummies to indicate whether a household possessed the assets or not. The following items were included in this analysis: radio, bicycles, mats/mattress, bed, blankets, sofa, table, chairs, television, and cell-phone.

¶The agriculture equipment index was constructed similarly to the above. The items included in the analysis were as follows: plough, sprayer, irrigation can, granary, treadle pump, ox-cart, hand hoe and panga knife.

‖1 US$ = MwK 390 (July 2014)

Notes: The test statistics are absolute values, t-tests for continuous variables and chi-square tests for nominal or categorical variables: *significant at $p < 0.1$, **significant at $p < 0.05$ and ***significant at $p < 0.001$
Source: Household survey (2014)

high cost of chemicals for crop protection (e.g. beetles in jatropha) and low farmgate prices.

Furthermore, the market for jatropha is not well developed in Malawi (Mponela *et al.*, 2011). Jatropha cultivating farmers decried lack of competition as another setback since BERL was the only buyer of jatropha seeds. To address some of the market related challenges, smallholders suggested engaging in pre-season interphase negotiations with potential buyers to attain (i) improved farm gate prices for jatropha in the following seasons, and (ii) improved commitment to strengthening marketing systems with more buyers.

The perceived level of food production was also lower for JCFs as compared to NJFs. The results showed that a significantly smaller percentage (24 %) of JCFs rated their food production as generally enough. Overall, jatropha cultivation was associated with large variations in household welfare measured as consumption expenditure per AEU. The welfare of JCFs was significantly lower by almost 20 percentage points compared to NJFs. While these results need to be interpreted with caution, competition for resources (family labour and purchased inputs), which might have been diverted away from agricultural production, could be another possible explanation for the low domestic food production.

Table 2: *Foster Greer Thorbecke (FGT) Poverty indices results showing percentage households under different poverty measures (n = 298).*

Parameter	*JCFs*	*NJFs*	*Difference*
Headcount ratio (%)			
Poverty line	40.6	26.7	13.9
Poverty line (+10 %)	44.8	34.7	10.1
Poverty gap ratio (%)			
Poverty line	11.7	8.1	3.6
Poverty line (+10 %)	14.7	10.2	4.5
Squared poverty gap ratio			
Poverty line	5.5	3.9	1.6
Poverty line (+10 %)	6.9	4.8	2.1

Notes: NJFs = non jatropha farmers, JCFs = jatropha cultivating farmers.
Source: Household Survey data (2014).

Table 2 compares levels of absolute (headcount) and relative poverty (gap ratio) using FGT indices between JCFs and NJFs. The FGT indices provide a glance at the welfare differences between JCFs and NJFs. For purposes of this study, a relevant local poverty line threshold measured in Malawi Kwachas developed by The National Statistical Office (NSO) was adopted and adjusted for inflation to K65,554 per adult equivalent per year (NSO, 2012). As a robustness test, another higher threshold pegged at 10 % above the poverty line value was also used to conduct a sensitivity test (Deaton, 1997).

Poverty incidence results reported in Table 2 suggest that 40 % of JCFs were categorised as poor, about 14 percentage points more than the NJFs. Similarly, the poverty gap ratio (11.7 %) and severity of poverty were also higher for JCFs as compared to their counterparts. The poverty gap result suggests that consumption expenditure for JCFs needed to rise by close to 12 % to reach the cut-off poverty line compared to 8 % for NJFs. The sensitivity analysis simulated at a higher poverty line (10 % above the poverty line) also showed a similar trend with more JCFs falling below the poverty line.

3.2 Econometric results

3.2.1 ESR estimates of determinants of welfare impacts of jatropha cultivation

The ESR model was estimated using the full information maximum likelihood method, which accounts for unobserved selection bias. The dependent outcome variable used to measure welfare was consumption expenditure per AEU. Table 3 presents estimated coefficients of covariates, their levels of significance and the extent to which they influenced welfare (further discussed in section 4.2).The model shows a good fit for the data and strongly confirms joint independence of all three equations (LR test; X^2 = 21.6***). The Wald test also confirmed that the coefficients as a group were significantly different between the two groups (X^2(12)= 64.1***).

The covariates exerted different effects on the outcomes between the two groups of farmers which showed presence of heterogeneity in the sample. The Rho(ρ) values were negative for both JCFs and NJFs outcome equations but significantly different from zero for NJFs only. The insignificance of the Rho(ρ) value for JCFs rejects the null hypothesis of presence of selection bias in the sample from unobservable factors, which could not be established *a priori*. The significance of the correlation coefficient Rho(ρ) between the selection equation and the welfare function of NJFs suggests that NJF welfare was higher than a randomly selected household who participated in jatropha cultivation (Tauer, 2005; Negash & Swinnen, 2013).

All four covariates that significantly influenced welfare among JCFs had the expected positive sign. These included: wealth (assets), agriculture equipment access, land and off-farm income access. The significant covariates in the NJFs equation also had the expected signs except for gender, which returned a negative sign, while farming experience was ambiguous *a priori*. Wealth (assets), land, agriculture equipment access, credit access and public phones were the significant factors for NJFs.

3.2.2 Impact of participation in jatropha cultivation

The results from conditional outcome expectations used to assess the base and transitional heterogeneity are presented in Table 4. The simulation exercise used consumption expenditure per AEU as the outcome variable. Values along the diagonals (i) and (iv) represent the observed mean values while (ii) and (iii) were the expected values for the counterfactual units. The treatment effect in the last column of

Table 3: *Full information maximum likelihood estimates of the switching regression model.*

	JCFs model		*NJFs model*	
Variable	*Coef.*	*Std. error*	*Coef.*	*Std. error*
Log farming experience	2,642	5,050.2	−12,675*	5,277.8
Effective labour	1,749	3,873.8	2,244.5	4,270
Household asset index	8,974.2*	3,509.3	11,247.4***	3,034.7
Land (ha)	7,306.7*	3,093.2	13,337***	3,455.4
Agric. equip index	6,405.8*	3,061.4	6,458.9***	2,899.3
Total livestock units	−151.4	873.7	5,847.1	4,389.1
Gender	13,148.6	8,512.2	−27,062.8*	8,720.7
Education endowment	−5,503.3	5,849.4	−4,093.1	6,878
Off-farm income	11,565.4*	6,981.7	−5,678	7,270.8
Soil fertility status	7,549.5	7,163.3	2,184.2	7,839.2
Public phones	122.8	263.8	−575.6*	302.6
Access to credit	4,610.7	7,505	16,835.5*	7,566.9
Constant	65,138*	30,864.9	117,607.6***	27,215.5
Sigma	30,469.6	2,857.2	52,815.5	3,330.5
Rho	−0.22		−0.93*	
Wald $X^2(12)$				64.1***
N				298
Likelihood ratio test for independence of equations				21.6***

Notes: NJFs = non jatropha farmers, JCFs = jatropha cultivating farmers. The test statistics are: T-test for model variables and chi-square for model diagnostic variables such as Wald statistics. The significance levels: * ($p < 0.1$), ** ($p < 0.05$) and *** ($p < 0.001$). Source: Household survey (2014)

Table 4: *Average expected consumption expenditure per adult equivalent unit for the decision to grow or not to grow jatropha (in Malawi kwachas (Mwk)).*

	Decision phase					
Category		*to grow*		*not to grow*		*treatment effect*
JCFs	(i)	79,975.1	(ii)	71,405.0	(v)	8,569.9
		(2,527.0)		(5,213.6)		
NJFs	(iii)	31,161.4	(iv)	96,441.7	(vi)	−65,280.3***
		(1,666.7)		(1,684.2)		
	BH 1 =	48,813.7	BH 2 =	−25,036.7	TH =	73,849.9

Notes: NJFs = non jatropha farmers, JCFs = jatropha cultivating farmers. Using notation, base heterogeneity (BH) is calculated as (i - iii) and (ii - iv), while transitional heterogeneity (TH) is (v-vi). Standard errors are in parentheses.
Source: Household Survey data (2014).

Table 4 represents the expected consumption expenditure per AEU for a randomly drawn household in their respective groups. The results show that participation was associated with an average increase in consumption expenditure per AEU (8,569.9 Kwachas). However, the effect was not statistically significant.

The expected outcome for the counterfactual scenario for NJFs showed large variations to the observed welfare. The results showed that consumption expenditure for NJFs would significantly decline if they had decided to grow jatropha (-65,280 Kwachas). These results suggests that NJFs were better-off in their choice of livelihood activities which earned them better welfare than if they decided to grow jatropha. Comparatively, the proportionate change in the expected effect of jatropha cultivation was significantly larger for NJFs relative to JCFs which explains the positive transitory heterogeneity effect (Asfaw *et al*., 2012).

Table 5: *Results of propensity score matching and nearest neighbour approaches in Malawi kwachas (Mwk).*

Matching algorithm	*ATE (Mwk/AEU)*	*Standard errors*	*Test statistics*	*Number of households*	
				treated	*untreated*
Propensity Score Matching	−12,354	5,458.2	2.26*	96	70
Nearest Neighbour	−16,828.6	8,301.8	2.03*	96	67

Notes: ATE refers to average treatment effect on the treated, and * stands for significance at the 10 % level of probability. Test statistics are absolute values.
Source: Household Survey data (2014).

As a robustness check, selection bias was also modelled as a function of only observable covariates. The insignificant correlation coefficient (Rho) for the JCFs equation (Table 3) satisfied the conditional independence assumptions, which entailed that PSM could be used to generate unbiased and robust results.

The results of PSM analysis presented in Table 5 showed presence of large variations in the consumption expenditure per AEU between JCFs and NJFs. Depending on the type of algorithm used, the margin was significantly lower for JCFs by either 12,354 or 16,828.6 Kwachas for PSM and NN matching techniques respectively.

The PSM technique used 70 untreated observations, while NN method selected 67 counterfactual households based on observable characteristics to match with the treated units. The results showed that the nearest neighbour and PSM estimates were similar which suggests that these results were consistent and robust.

4 Discussion

4.1 Foster Greer Poverty index analysis

A comparative assessment of household poverty profiles gave a snapshot of the general welfare of JCFs and NJFs households. The absolute and relative poverty were more widespread among JCFs compared to NJFs. A possible explanation can be found by scrutinising the outcomes of the livelihood strategies of the two groups. The results in Table 1 showed that JCFs produced significantly less food and received less income from crop sales compared to NJFs. While most of the JCFs considered farming as their primary occupation (87 %), the ranking of fishing activities ahead of farming during focus group discussion underscores the relative importance of the fishing industry in their livelihoods (see Appendix 1: Supplementary material). Fishing and the earnings from the activities thereof are spread almost throughout the year, except for the closed-seasons when fish breed (April to May), which could explain the perceived higher ranking over rainfed agriculture. Nonetheless, these results suggest that the net benefits from these activities were comparatively lower relative to NJFs livelihoods. These results differ from Mudombi *et al.* (2016) who did not find any variations using multidimensional poverty indices between jatropha farmers and the untreated group. The multidimensional indices approach used a broader scope, which included access to safe drinking water, sanitation, electricity, and human capital development indicators like the level of education, among others. It has also been indicated that this approach hinged on long-term asset accumulation; therefore, it would be more suitable for investments which were established over a relatively longer period (e.g. sugarcane plantations) rather than the recently established jatropha projects.

4.2 Determinants of household welfare impacts of jatropha cultivation

The FIML switching regression estimates showed that the covariate effects were heterogeneous between JCFs and NJFs. Land availability defines the household's production frontier to expand existing activities or diversify into other enterprises. Land holdings had a positive and significant effect on the welfare of both farmer categories. However, the coefficient estimates in Table 3 showed that relative to NJFs, JCFs were likely to benefit less for every additional hectare of land. Relative to JCFs, the NJFs group earned substantially more income from crop sales, which probably suggests that they enjoyed higher productivity since land and domestic labour endowments were not significantly different between the two groups. Focus group discussions also revealed that farming (rainfed and wetland) was ranked the most important livelihood strategy for NJFs. Winter season cultivation was also an important livelihood activity which suggest that NJFs spent more time on agricultural activities per year while JCFs ranked it second to fishing. Based on prior recommendations, jatropha was planted mostly in hedgerows around farmers' fields and marginal lands. While other studies suggest adequate land is important for intensification of a technology (Soto *et al.*, 2015), this may not necessarily always be the case for jatropha based on the planting recommendations stated above. Nonetheless, another study in Malawi found that land size had a positive influence on both adoption and extent of jatropha cultivation (Mapemba *et al.*, 2013).

Access to off-farm income was significantly associated with the probability of higher welfare for JCFs only. Off-farm earning opportunities offer a diversified income base to smallholders mostly used to augment household incomes and expenditure gaps. These results are consistent with previous studies which found that off-farm earning opportunities were positively associated with higher welfare in Ghana, Ethiopia, and Tanzania (Asmah, 2011; Asfaw *et al.*, 2012). Mangochi district has a wide diversity of livelihood options (including primary fishing, pulling fishnets, small scale trading, and wage employment) (see Appendix 1: Supplementary material). The high opportunity cost of labour potentially limits labour availability in agricultural activities (Katengeza *et al.*, 2012). However, the overall poverty profile result (Table 2) suggests that earnings in the fishing value-chain and other off-farm earning activities practised by JCFs were not very lucrative. Grass & Zeller (2011) reported a similar finding in Madagascar where households with higher labour opportunity cost (running own businesses, etc.) were unlikely to offer their labour in jatropha plantations.

Access to agricultural equipment was significant and positively associated with higher welfare for JCFs. These results also suggest that JCFs would benefit more from increased access to productive assets. Agricultural equipment, such as sprayers and ploughs, are essential to improve crop protection, productivity, and labour efficiency, which increase productivity, yields, and eventually farm revenues. JCFs had significantly lower access to agricultural equipment compared to NJFs (see Table 1) which might be explained by the structure and the relative importance of their livelihood strategies (see Appendix 1: Supplementary material). Competition between livelihood activities, depending on their perceived importance, may divert away scarce resources from investment in farming equipment into other tools (e.g. fishing gear).

Household durable assets, a proxy for household wealth status, was significantly and positively associated with higher welfare for both JCFs and NJFs. While wealthier households may have more resources for investment in agricultural innovations, the relatively low levels of equipment and management required for jatropha production, processing and marketing enable even resource-poor smallholders to participate as feedstock producers. This is supported by Mujeyi (2009) who also reported that jatropha required less technology and management to produce and market which may not necessarily appeal to high-end wealthier farmers.

4.3 *Welfare impacts of jatropha cultivation using ESR and PSM*

The observed average outcome differences in consumption expenditure per AEU for the JCFs was lower as compared to NJFs by almost 20 %. This simple analogy can be misleading as not all factors that defined consumption expenditure were known. Conditional expected outcomes account for the systemic variations which could not be addressed solely by observable characteristics as determinants of welfare.

The results also showed presence of heterogeneity in the sample and displayed self-sorting of smallholders into their best livelihood options based on their expected net benefits. The simulation exercise also showed that the welfare of NJFs was expected to decline (84 % reduction) if they decided to cultivate jatropha while the outcome for JCF was at best zero. Overall, these results suggest that there was no evidence of significant net benefits from jatropha cultivation to smallholders. Moreover, the descriptive statistics (Table 1) showed that NJFs earned more income from crop sales than JCFs, suggesting that additional income flows from jatropha cultivation were insufficient to boost their expenditure. This is supported by Mudombi *et al.* (2016) who reported that JCFs had so far received insufficient income to meaningfully impact on poverty reduction.

The results from PSM analysis do not support the notion that jatropha cultivation has significant welfare benefits for participating households. The PSM results returned statistically significant lower welfare outcomes for JCFs when compared to a statistically constructed counterfactual sample based on observable characteristics. These results differ from the ESR treatment effect on the treated estimates which showed that the welfare benefits were at best zero. A possible explanation could be attributed to the fact the PSM is based on pre-treatment observable characteristics only. Nonetheless, PSM results from the two algorithms were consistent and robust which suggests that it was more efficient at addressing the selection bias.

5 Conclusion

This study evaluated the welfare impacts of jatropha cultivation measured as consumption expenditure per AEU for smallholders in southern Malawi. It addressed the potential selection bias by employing the endogenous switching regression model and propensity score matching techniques.

The results showed that when selection bias was controlled from both observed and unobserved covariate effects, welfare impacts of jatropha cultivation were lower compared to the untreated group. This study concluded that there was no empirical evidence to support the perceived welfare impacts of jatropha cultivation at the current technology level (indigenous germplasm), know-how (commonly employed agronomic practices) and current business models in Malawi. Thus, for jatropha to contribute to rural household welfare, future research has to focus on the development and dissemination of a portfolio of more profitable technology/practice packages. In the absence of clear tangible welfare benefits of jatropha cultivation to smallholders under current conditions, jatropha is unlikely to bring meaningful welfare benefits to rural smallholders. However, the global momentum in pursuit of environmentally friendly fuels to reduce the carbon footprint is likely to be sustained into the foreseeable future. As such, future research focus on other potential non-food feedstocks like 'Moringa' (*Moringa oleifera*) could also be explored further as potential biofuels options for Malawi.

It is also worth noting that biofuels are not a panacea to rural development and welfare of smallholders. The results on determinants of household welfare from this study corroborate previous studies on influence of assets on welfare. Investments into initiatives that promote asset building need to be encouraged alongside other rural development interventions to improve the welfare of smallholders.

Supplement

The supplementary material related to this article is available online on the same landing page at: https://doi.org/10.17170/kobra-20191030734 .

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Conflict of interest

Authors state they have no conflict of interests.

References

Achten, W. M. J., Maes, W. H., Aerts, R., Verchot, L., Trabucco, A., Mathijs, E., Singh, V. P. & Muys, B. (2010). Jatropha: From global hype to local opportunity. *Journal of Arid Environments*, 74 (1), 164–165.

Achten, W. M. J., Verchot, L., Franken, Y. J., Mathijs, E., Singh, V. P., Aerts, R. & Muys, B. (2008). Jatropha bio-diesel production and use. *Biomass and Bioenergy*, 32 (12), 1063–1084.

Ajanovic, A. (2011). Biofuels versus food production: Does biofuels production increase food prices? *Energy*, 36 (4), 2070–2076.

Ambali, A., Chirwa, P. W., Chamdimba, O. & Zyl, W. H. v. (2011). A review of sustainable development of bioenergy in Africa: An outlook for the future bioenergy industry. *Scientific Research and Essays*, 6 (8), 1697–1708.

Asfaw, S., Shiferaw, B., Simtowe, F. & Lipper, L. (2012). Impact of modern agricultural technologies on smallholder welfare: Evidence from Tanzania and Ethiopia. *Food Policy*, 37 (3) 283–295.

Asmah, E. E. (2011). Rural livelihood diversification and agricultural household welfare in Ghana. *Journal of Development and Agricultural Economics*, 3 (7), 325–334.

Brittaine, R. & Lutaladio, N. (2010). Jatropha: a smallholder bioenergy crop: The potential for pro-poor development. Food and Agriculture Organization of the United Nations (FAO), Rome. Italy.

Deaton, A. (1997). The analysis of household surveys: A microeconometric approach to development policy. Johns Hopkins Univ. Press, Baltimore, for the World Bank.

Di Falco, S., Veronesi, M. & Yesuf, M. (2011). Does adaptation to climate change provide food security? A microperspective from Ethiopia. *American Journal of Agricultural Economics*, 93 (3), 825–842.

Ewing, M. & Msangi, S. (2009). Biofuels production in developing countries: assessing tradeoffs in welfare and food security. *Environmental Science & Policy*, 12 (4), 520–528.

Gasparatos, A., Lee, L. Y., Von Maltitz, G. P., Mathai, M. V., Puppim de Oliveira, J. & Willis, K. J. (2012). Biofuels in Africa: Impacts on ecosystem services, biodiversity and human well-being. United Nations University Institute of Advanced Studies, Yokohama.

Gasparatos, A., von Maltitz, G. P., Johnson, F. X., Lee, L., Mathai, M., Puppim de Oliveira, J. A. & Willis, K. J. (2015). Biofuels in sub-Sahara Africa: Drivers, impacts and priority policy areas. *Renewable and Sustainable Energy Reviews*, 45, 879–901.

Government of Malawi, (2013). Annual economic report. Ministry of Economic Planning and Development, Lilongwe.

Grass, M. & Zeller, M. (2011). Rural employment and Income effects of a Jatropha plantation in Madagascar. *Quarterly Journal of International Agriculture*, 50 (4), 347–368.

Herrmann, R. , Jumbe, C. , Bruentrup, M. & Osabuohien, E. (2017). Competition between biofuel feedstock and food production: Empirical evidence from sugarcane outgrower settings in Malawi. *Biomass and Bioenergy*, 114, 100–111.

Hodbod, J. & Tomei, J. J. G. C. (2013). Demystifying the social impacts of biofuels at local levels: Where is the evidence? *Geography Compass*, 7 (7), 478–488.

Jumbe, C. B. L. & Mkondiwa, M. (2012). Comparative analysis of biofuels policy development in sub-Saharan Africa: The place of private and public sectors. *Renewable Energy*, 50, 614–620.

Jumbe, C. B. L. , Msiska, F. B. M. & Madjera, M. (2009). Biofuels development in sub-Saharan Africa: Are the policies conducive? *Energy Policy*, 37 (11), 4980–4986.

Kant, P. & Wu, S. (2011). The extraordinary collapse of Jatropha as a global biofuel. *Environtal Science & Technology*, 45 (17), 7114–7115.

Katengeza, S., Mangisoni, J. H., Kassie, G. T., Sutcliffe, C., Langyintuo, A., La Rovere, R. & Mwangi, W. (2012). Drivers of improved maize variety adoption in drought prone areas of Malawi. *Journal of Development and Agricultural Economics*, 4 (14), 393–403.

Khandker, S. R., Koolwal, G. B. & Samad, H. A. (2010). Handbook on impact evaluation: Quantitative methods and practices. World Bank Publications.

Kuntashula, E. & Mungatana, E. (2013). Estimating the causal effect of improved fallows on farmer welfare using robust identification strategies in Chongwe, Zambia. *Agroforestry Systems*, 87 (6), 1229–1246.

Ligon, E. & Schechter, L. (2003). Measuring vulnerability. *The Economic Journal*, 113 (486), C95–C102.

Lokshin, M. & Sajaia, Z. (2004). Maximum likelihood estimation of endogenous switching regression models. *Stata Journal*, 4, 282–289.

Maddala, G. S. (1983). Limited-dependent and qualitative variables in econometrics. Cambridge university press, Cambridge.

Makungwa, S., Chittock, A., Skole, D., Kanyama-Phiri, G. & Woodhouse, I. (2013). Allometry for Biomass Estimation in Jatropha Trees Planted as Boundary Hedge in Farmers' Fields. *Forests*, 4 (2), 218–233.

Mapemba, L. D., Grevulo, J. A. & Mulagha, A. M. (2013). What drives adoption of biofuel (*Jatropha curcas*) production in central eastern Malawi? *Journal of Energy Technologies & Policy*, 3 (10), 75–92.

Mponela, P. , Jumbe, C. B. L. & Mwase, W. F. (2011). Determinants and extent of land allocation for Jatropha curcas L. cultivation among smallholder farmers in Malawi. *Biomass and Bioenergy*, 35 (7), 2499–2505.

Mudombi, S., Von Maltitz, G. P., Gasparatos, A., Romeu-Dalmau, C., Johnson, F. X., Jumbe, C., Ochieng, C., Luhanga, D., Lopes, P., Balde, B. S. & Willis, K. J. (2016). Multi-dimensional poverty effects around operational biofuel projects in Malawi, Mozambique and Swaziland. *Biomass and Bioenergy*, 114, 41–54.

Mujeyi, K. (2009). Socio-Economics of Commercial Utilization of Jatropha (*Jatropha curcas* L.) In Mutoko District, Zimbabwe. *Journal of Sustainable Development in Africa*, 11 (2), 36–53.

Mwakaje, A. G. (2012). Can Tanzania realise rural development through biofuel plantations? Insights from the study in Rufiji District. *Energy for Sustainable Development*, 16 (3),320–327.

Nalivata, P. & Maonga, B. B. (2011). Understanding biofuel status in Malawi, unlocking the myths and truths! Lilongwe, Malawi. 137 p.

Negash, M. & Swinnen, J. F. M. (2013). Biofuels and food security: Micro-evidence from Ethiopia. *Energy Policy*, 61, 963–976.

NSO, (2012). Integrated Household Survey 2010-2011, Household Socio-economic Characteristics Report. National Statistical Office, Zomba. Malawi.

NSO. (2014). Malawi Labour Force Survey 2013. National Statistical Office. Zomba, Malawi.

Pradhan, A. & Mbohwa, C. (2014). Development of biofuels in South Africa: Challenges and opportunities. *Renewable and Sustainable Energy Reviews*, 39, 1089–1100.

Romeu-Dalmau, C., Gasparatos, A., von Maltitz, G., Graham, A., Almagro-Garcia, J., Wilebore, B. & Willis, K. J. (2016). Impacts of land use change due to biofuel crops on climate regulation services: Five case studies in Malawi, Mozambique and Swaziland. *Biomass and Bioenergy*, 114, 30–40.

Schuenemann, F., Thurlow, J. & Zeller, M. (2016). Leveling the field for biofuels: Comparing the economic and environmental impacts of biofuel and other export crops in Malawi. *Agricultural Economics*, 48 (3),301–315.

Sen, A. (1981). Ingredients of famine analysis: availability and entitlements. *Quarterly Journal of Economics*, 96 (3), 433–464.

Sinyolo, S., Mudhara, M. & Wale, E. (2014). The impact of smallholder irrigation on household welfare: The case of Tugela Ferry irrigation scheme in KwaZulu-Natal, South Africa. Water SA, 40 (1), 145–156.

Soto, I., Achten, W. M., Muys, B. & Mathijs, E. (2015). Who benefits from energy policy incentives? The case of jatropha adoption by smallholders in Mexico. *Energy Policy*, 79 (C), 37–47.

Tauer, L. (2005). The impact of recombinant bovine somatotropin on dairy farm profits: A switching regression analysis. *AgBioForum*, 8 (1), 33–39.

van de Walle, D. (2013). Lasting Welfare Effects of Widowhood in Mali. *World Development*, 51, 1–19.

von Maltitz, G., Gasparatos, A. & Fabricius, C. (2014). The rise, fall and potential resilience benefits of Jatropha in Southern Africa. *Sustainability*, 6 (6), 3615–3643.

von Maltitz, G., Gasparatos, A., Fabricius, C., Morris, A. & Willis, K. (2016). Jatropha cultivation in Malawi and Mozambique: impact on ecosystem services, local human well-being, and poverty alleviation. *Ecology and Society*, 21 (3), 3.

Wooldridge, J. M. (2002). Econometric Analysis of Cross Section and Panel Data. Cambridge, Massachusetts London, England: The MIT Press.