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Adoption of ox-drawn minimum tillage ripping by smallholder farmers in Zambia

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ABSTRACT

Applying a triple hurdle model to nationally representative farm household data from Zambia, this study examines determinants associated with three sequential crop production decisions: animal draught power adoption, minimum tillage ripping adoption, and the extent of hectares ripped. The correlated random effects estimator is also used to explore two dimensions of minimum tillage ripping adoption: changes in adoption within a household over time (within-household effect) and differences in adoption between households at a given time (between-household effect). Results reveal that age and gender of the household head, the head's level of education, household labour, hectares cultivated, ripper ownership, loan access, receiving conservation farming advice and distance to agricultural service providers are some of the key determinants associated with the three stages investigated using the triple hurdle model. The correlated random effects results demonstrate that while certain factors enhance or inhibit the expected value of hectares ripped within a given household, it is not always the case that these factors have a similar effect when the analysis is between households. This article highlights policy options to enhance ownership of rippers, support smallholder farmer access to loans, facilitate development of agro-dealer networks, and innovative approaches for disseminating conservation farming information to farmers.

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1. Introduction

Promotion of agricultural innovations has long been championed as a key strategy to transform smallholder agricultural production and productivity in sub-Saharan Africa (SSA). In a seminal paper published more than three decades ago on agricultural innovations in developing countries, Feder, Just, and Zilberman (1985) alluded to the attention that agricultural innovations received in the development discourse of that era. They attributed this interest to the potential that technology has to substantially increase production and incomes of farmers. With the world population doubling over the last 40 years coupled with the negative effects of climate change, finding innovative ways that promote agricultural production and productivity in a sustainable manner has become top of the agenda for policy makers, development practitioners and scholars.

Yet, adoption of a number of agricultural technologies continues to remain low in developing countries, particularly in sub-Saharan Africa (SSA). In an extensive review of microstudies analyzing adoption of agricultural technologies, Doss (2006) suggests three main reasons why farmers do not

adopt improved technologies. First, farmers are generally not aware of existing technologies and the benefits that come with adopting them. Second, technologies are either not readily available or not available at the time they are needed by intended users. Third, technologies end up not being profitable because of the complex set of factors that farmers grapple with such as factor input allocation challenges and the policy environment. At macro level, Odame et al. (2011) attribute low adoption of agricultural technologies to factors related to performance of the technologies, their delivery and management mechanisms, farmer access to extension and other support services, effectiveness of market systems, inadequate attention to gender-based constraints such as women's heavy workload and their limited access to and control of key factors of production, and the overall policy institutional processes responsible for creating an enabling environment for adoption.

Conservation agriculture is one example of a potentially good innovation for smallholder production systems that, despite widespread promotion in parts of sub-Saharan Africa, has been characterised by low adoption rates (Grabowski et al. 2016). In Zambia, the focus of our study, national level estimates of minimum tillage adoption rates in 2015 stood at 3.8% and 3.4% for planting basins and ripping respectively (Zulu, Chapoto, and Hichaambwa 2016). Yet, adoption of animal draught power (ADP) stood at 36.5% in the same year (IAPRI 2015). As a technology, conservation agriculture (CA) or conservation farming (CF)¹ as it is known in some literature, involves a set of agronomic practices that have potential to mitigate soil degradation and improve crop productivity (Giller et al. 2009). The practices include dry-season minimum tillage (using hand hoes, ox-drawn rippers or tractor rippers), crop residue retention and nitrogen-fixing crop rotations (CFU 2007a, 2007b). Farmers adopting all three practices are categorised as full adopters while those practicing minimum tillage (MT) in combination with one of the other two practices are classified as partial CF adopters (Zulu, Chapoto, and Hichaambwa 2016).

With substantial investment made towards promotion of CA by the public and private sectors in SSA in the last 20 years, understanding the drivers of adoption of the technology, coupled with tracking the levels of its adoption, have been matters of empirical interest among scholars. In a meta-study by Nkala et al. (2011) on the hindrances to successful implementation of CA in Southern Africa, their study points to a number of constraining factors that have limited widespread adoption. These include lack of relevant infrastructure, insufficient involvement of farmers in the process, existing livestock management norms, imperfect input and credit markets and weak land tenure systems. A number of studies have also shown that availability of labour during land preparation and weeding is key to adoption of CA (Baudron et al. 2007; Haggblade and Tembo 2003; Umar et al. 2011; Mazvimavi 2011; Vasanthakumar, Ramasubramanian, and Hansra 2017) while others have demonstrated that farm size, household size and access to extension services and training also play a pivotal role in adoption (Nasrin and Akteruzzaman 2017; Belachew, Mekuria, and Nachimuthu 2020). In a study of minimum tillage adoption among commercial cotton farmers in Eastern Zambia between 2002 and 2011, Grabowski et al. (2014) found that demonstration effects of lead farmers, availability of herbicides and long-term extension effects influenced adoption of MT in that part of the country. Despite these important findings, their study revealed that adoption of CA among cotton farmers marginally increased from 11% to 13% between 2002 and 2011.

Our study is located within this strand of literature but with a focus on ox-drawn minimum tillage ripping (MTR). In this article, we adapt the "triple hurdle" approach, similar to the one used by Burke, Myers, and Jayne (2015), to unpack the factors that determine adoption of ox-drawn MTR in Zambia. Although it is not the first of its kind to interrogate MTR determinants (see Grabowski et al. 2014 or Zulu, Chapoto, and Hichaambwa 2016), our paper adds to the body of knowledge in the following ways. First, we examine a farmer's decision whether or not to adopt animal draught power. Second, we model the farmer's decision whether or not to adopt MTR conditional on adopting ADP. Third, we estimate the intensity of ripping (defined here as land prepared, in hectares, for crop production) conditional on the decision to adopt ADP and MTR. In addition, we extend our investigation by using the correlated random effects (CRE) estimator to estimate the unconditional average partial effects (APEs) on hectares ripped in order to explore the within and between household effects.

The triple hurdle approach adapted in this paper recognises the fact that the decisions of whether or not to use ADP and MTR by farmers are part of a single process that should be jointly analysed. If a double hurdle approach is employed where the first hurdle is set up to examine the decision to use or not to use MTR and the second hurdle examines the decision of how much land to prepare for crop production conditional on MTR adoption, the analysis would only focus on the population of ADP adopters leaving out ADP non-adopters. In such a case, it would be difficult to know if the factors that encourage MTR adoption among ADP adopters would also induce ADP non-adopters to begin using ADP and MTR subsequently. This is because using the double hurdle approach, as motivated above, leaves out potential ADP users, making inferences drawn from such an approach not generalisable to the entire population of agricultural households when potential ADP adopters exist. To the best of our knowledge, this triple hurdle approach has not been used in this context of determining the key drivers of minimum tillage adoption.

The rest of the paper is organised as follows: section 2 discusses the conceptual framework, while data and the empirical strategy are presented in section 3. Section 4 presents and discusses the results of the study and section 5 concludes.

2. Conceptual framework

Based on theoretical and empirical studies on adoption of improved technologies, this study postulates that adoption of ox-drawn MTR is influenced by a number of exogenous factors. The factors are divided into four categories: (1) household characteristics such as gender, age, education of the household head and labour availability at household level; (2) farm characteristics (ownership of productive assets, hectares cultivated, distance to agricultural service providers); (3) institutional factors which include extension advice designed for specific improved technologies, loan access and factor input prices and; (4) locational factors such as province.

Adoption of agricultural technologies is influenced by several interrelated components within the decision environment in which farmers operate. Adoption of improved technology by farmers will depend on the benefits that the farmer derives from that technology and the awareness of the technology. The farmer will adopt the new technology only if the incentives outweigh the disincentives. Successful and continued adoption of the new technology depends on farmers' perception of the incentives and disincentives provided along with that technology. If perceived benefits are higher than the costs, farmers are motivated to adopt a technology as they expect high returns on investment. Thus, this study was guided by the utility maximisation theory (the von Neumann-Morgenstern's utility theory). The theory posits that the decision to "adopt" or "not adopt" is based on whether the new technology will bring more utility to farm households than the technology currently being used (Caviglia-Harris 2003). Farmers are expected to choose technologies that give them maximum utility. Examples of studies that have used the theory to examine adoption of improved technologies include Ogada, Mwabu, and Muchai (2014) and Borges, Foletto, and Xavier (2015).

3. Data and methods

3.1 Data sources

We use nationally representative secondary data known as the Rural Agricultural Livelihoods Survey (RALS) conducted in 2012 and 2015 (hereafter referred to as 2012 RALS and 2015 RALS respectively) by the Indaba Agricultural Policy Research Institute (IAPRI) among farming households in Zambia. During both waves, the survey was conducted in collaboration with the Central Statistical Office (CSO) and the Ministry of Agriculture and Livestock (MAL). The 2015 RALS is a panel survey continuing from the 2012 RALS survey whose sampling frame was based on the 2010 Census of Housing and Population in Zambia. Using a stratified two-stage sampling design where the primary sampling

units were standard enumeration areas and the secondary sampling units were households, a total of 8840 households were interviewed during the 2012 wave. In 2015, a total of 7934 households were interviewed; 7254 households were those who were also interviewed in 2012 (representing an attrition rate of 17.9%) while 660 were new households added during the 2015 wave. Therefore, the pooled sample of panel households was 16,094. In our analysis, we used 14,213 households (7130 and 7083 from 2012 and 2015 respectively) after dropping households with missing information on critical variables.

Both surveys involved collection of information on demographic characteristics, crops, land use, assets, adoption of technologies, agriculture information, agroforestry, and other relevant aspects that affect livelihoods of smallholder farmers in Zambia. The variables considered in this study were selected based on the review of past theoretical and empirical adoption studies that focused on ADP adoption (see Mbata James 2001; Guthinga, Karugia, and Nyikal 2007; Cachomba et al. 2011; Okello et al. 2015; Makki, Eltayeb, and Badri 2017) and those that looked at CF adoption (see Nzomoi et al. 2007; Egyir 2010; Odoemenem 2010; Beltran et al. 2011; Chikoye, Schultz, and Ekeleme 2004; Mohammad and Noorul 2004; Gianessi and Williams 2011; Ng'ombe et al. 2014; Bryan et al. 2009; Chomba 2004; Haggblade, Kabwe, and Plehoples 2011; Umar et al. 2011; Mavunganzidze et al. 2013; Belachew, Mekuria, and Nachimuthu 2020). Table 1 provides a detailed description of all the variables used in this article's analysis.

Table 1. Description of variables used in the analysis.

Variable name	Variable description
<i>Household characteristics</i>	
Gender of household head	Male headed Household (=1, if male, 0 o/w)
No education	Uneducated household head (0 years of formal education) (=1, if yes, 0 o/w)
Primary	Primary level of education of the head (1–7 years of formal education) (=1, if yes, 0 o/w)
Secondary	secondary level of education of the head (8–12 years of formal education) (=1, if yes, 0 o/w)
Tertiary	Tertiary level of education of the head (above 12 years of formal education) (=1, if yes, 0 o/w)
Labour availability ^a	Labour availability in adult equivalents
Age of head	Age of the household head in years
Age squared	Age of the household head squared
<i>Farm characteristics</i>	
Ownership of a ripper	Household owns a ripper (=1, if yes, 0 o/w)
Hectares cultivated	Hectares of land cultivated (Ha cult)
Tropical livestock units (TLU) ^b	Livestock units measured in terms of tropical livestock units
Distance to seller of vet products	Distance to seller of vet products (km)
Distance to extension officer	Distance to extension officer (km)
Distance to nearest agro-dealer	Distance to nearest agro-dealer (km)
<i>Institutional factors</i>	
Receive CF advice dummy	Household receive advice on CF (receive = 1, 0 o/w)
Loan access	Does the Household have access to loans (access = 1, 0 o/w)
Price of fertiliser per Kg	Input Price of fertiliser per kg in Kwacha
<i>Location of the farm</i>	
Central province	Province where farm is. (Central = 1, 0 o/w)
Copperbelt province	Province where farm is. (Copperbelt = 1, 0 0/w)
Eastern province	Province where farm is. (Eastern = 1, 0 0/w)
Luapula province	Province where farm is. (Luapula = 1, 0 0/w)
Lusaka province	Province where farm is. (Lusaka = 1, 0 0/w)
Muchinga province	Province where farm is. (Muchinga = 1, 0 0/w)
Northern province	Province where farm is. (Northern = 1, 0 0/w)
North-western province	Province where farm is. (North-western = 1, 0/w)
Southern province	Province where farm is. (Southern = 1, 0 0/w)
Western province	Province where farm is. (Western = 1, 0 0/w)

^aThe labour availability variable was generated using adult equivalent units. In this paper, we used the approach used by Storck et al. (1991) to generate adult equivalents. Each household member was assigned a weight based on age and gender. For both male and female household members younger than 10 years, the weight was equal to 0.6. For members between 10 and 13 years, the weight was equal to 0.9 for males and 0.8 for females. For members older than 13 years, the weight was equal to 1 for males and 0.75 for females.

^bTLU variable was generated using the following conversion factors: cattle = 1, pigs = 0.4, goats and sheep = 0.2 and donkeys = 0.6.

3.2 Empirical strategy

To measure the factors influencing ADP adoption, MTR adoption and the number of hectares ripped, the data were applied to a triple hurdle model. The likelihood function for the triple-hurdle model is an integration of a probit model in the first two hurdles and a lognormal model in the third hurdle. Previous studies that have used these hurdle models include those that have integrated the probit and lognormal model (Cragg 1971), those integrating the ordered probit and truncated normal model (Bellemare and Barrett 2006), and those integrating the probit model in the first hurdle, an ordered probit model in the second hurdle and two lognormal models in the third (Burke, Myers, and Jayne 2015). In this article, the triple hurdle model used is a probit-probit-lognormal model represented by the following full likelihood function:

$$f(w_1, w_2, y | \mathbf{x}\theta) = [1 - \Phi(\mathbf{x}_1\boldsymbol{\beta})]^{1[w_1=0]} \times \left[\Phi(\mathbf{x}_1\boldsymbol{\gamma}) \left[[1 - \Phi(\mathbf{x}_2\boldsymbol{\gamma})]^{1[w_2=0]} \left[\Phi(\mathbf{x}_2\boldsymbol{\gamma}) \frac{\phi[\log(y) - \mathbf{x}_3\boldsymbol{\delta}]/\sigma}{y\sigma} \right]^{1[w_2=1]} \right] \right]^{1[w_1=1]} \quad (1)$$

where $w_1 = 1$ if the household adopts ADP (passes the first hurdle), and $w_1 = 0$ if otherwise; $w_2 = 1$ if the household adopts MTR (passes the second hurdle), and $w_2 = 0$ if otherwise; y is the continuous variable for hectares ripped that can only be positive if the observation passes both hurdles. $\boldsymbol{\beta}$ is the vector of first stage parameters, and \mathbf{x}_1 is the vector of determinants for w_1 ; given that $w_1 = 1$, $\boldsymbol{\gamma}$ is the vector of parameters in the second stage, and \mathbf{x}_2 is the vector of determinants for w_2 ; and given $w_1 = w_2 = 1$ (which is to say, given that $y > 0$), $\boldsymbol{\delta}$ is the vector of parameters in the third stage, and \mathbf{x}_3 is the vector of determinants for y . For notational purposes, $\boldsymbol{\theta} = (\boldsymbol{\beta}, \boldsymbol{\gamma}, \boldsymbol{\delta})$ and $\mathbf{x} = (\mathbf{x}_1, \mathbf{x}_2, \mathbf{x}_3)$. The function Φ is the standard normal cumulative distribution, and ϕ is the standard normal probability density function. σ is the standard deviation of the random variable y .

Taking the log of this, the log-likelihood function for any given observation (i), is:

$$\begin{aligned} \ell_i(\boldsymbol{\theta}) &= \log \{1 - \Phi(\mathbf{x}_{1i}\boldsymbol{\beta})\}, && \text{if } w_1 = 0 \\ &= \log \{\Phi(\mathbf{x}_{1i}\boldsymbol{\beta})[1 - \Phi(\mathbf{x}_{2i}\boldsymbol{\gamma})]\}, && \text{if } w_1 = 1 \text{ \& } w_2 = 0 \\ &= \log \left\{ \Phi(\mathbf{x}_{1i}\boldsymbol{\beta})\Phi(\mathbf{x}_{2i}\boldsymbol{\gamma}) \left[\frac{\phi[\log(y_i) - \mathbf{x}_{3i}\boldsymbol{\delta}]/\sigma}{y_i\sigma} \right] \right\}, && \text{if } w_1 = 1 \text{ \& } w_2 = 1 \end{aligned} \quad (2)$$

This yields the following key probability equations:

$$\Pr(w_{1i} = 0 | \mathbf{x}_{1i}) = 1 - \Phi(\mathbf{x}_{1i}\boldsymbol{\beta}) \quad (3)$$

$$\Pr(w_{1i} = 1 | \mathbf{x}_{1i}) = \Phi(\mathbf{x}_{1i}\boldsymbol{\beta}) \quad (4)$$

$$\Pr(w_{1i} = 1, w_{2i} = 0 | \mathbf{x}_{1i}, \mathbf{x}_{2i}) = \Phi(\mathbf{x}_{1i}\boldsymbol{\beta})[1 - \Phi(\mathbf{x}_{2i}\boldsymbol{\gamma})] \quad (5)$$

$$\Pr(w_{1i} = 1, w_{2i} = 1 | \mathbf{x}_{1i}, \mathbf{x}_{2i}) = \Phi(\mathbf{x}_{1i}\boldsymbol{\beta})\Phi(\mathbf{x}_{2i}\boldsymbol{\gamma}) \quad (6)$$

and the following key expected values. First, the conditional expected value of y :

$$E(y_i | y_i > 0, \mathbf{x}_{3i}) = \exp\left(\mathbf{x}_{3i}\boldsymbol{\delta} + \frac{\sigma^2}{2}\right) \quad (7)$$

and the, so called, unconditional expected value of y :

$$E(y_i | \mathbf{x}_i) = \Phi(\mathbf{x}_{1i}\boldsymbol{\beta})\Phi(\mathbf{x}_{2i}\boldsymbol{\gamma})\exp\left(\mathbf{x}_3\boldsymbol{\delta} + \frac{\sigma^2}{2}\right) \quad (8)$$

If there are no interaction terms to consider, the marginal effect of a variable, x_k that is an element of x_1 , x_2 and x_3 on the unconditional expected value of y is:

$$\begin{aligned} \frac{\partial E(y_i | \mathbf{x}_i)}{\partial x_k} &= \beta_k \phi(\mathbf{x}_{1i} \boldsymbol{\beta}) \Phi(\mathbf{x}_{2i} \boldsymbol{\gamma}) \exp\left(\mathbf{x}_3 \boldsymbol{\delta} + \frac{\sigma^2}{2}\right) \\ &+ \gamma_k \Phi(\mathbf{x}_{1i} \boldsymbol{\beta}) \phi(\mathbf{x}_{2i} \boldsymbol{\gamma}) \exp\left(\mathbf{x}_3 \boldsymbol{\delta} + \frac{\sigma^2}{2}\right) \\ &+ \delta_k \Phi(\mathbf{x}_{1i} \boldsymbol{\beta}) \Phi(\mathbf{x}_{2i} \boldsymbol{\gamma}) \exp\left(\mathbf{x}_3 \boldsymbol{\delta} + \frac{\sigma^2}{2}\right) \end{aligned} \quad (9)$$

When the explanatory variables include interaction terms, the marginal effect is slightly different. For example, suppose one variable enters the equation as a quadratic term so that $\mathbf{x}_{1i} \boldsymbol{\beta} = \beta_1 x_1 + \dots + \beta_k x_k + \beta_{q1} x_q + \beta_{q2} x_q^2$ (and x_q is similarly included as a quadratic term in \mathbf{x}_2 and \mathbf{x}_3), then the marginal effect of x_q on the unconditional expected value of y is:

$$\begin{aligned} \frac{\partial E(y_i | \mathbf{x}_i)}{\partial x_q} &= (\beta_{q1} + 2\beta_{q2} x_{qi}) \phi(\mathbf{x}_{1i} \boldsymbol{\beta}) \Phi(\mathbf{x}_{2i} \boldsymbol{\gamma}) \exp\left(\mathbf{x}_3 \boldsymbol{\delta} + \frac{\sigma^2}{2}\right) \\ &+ (\gamma_{q1} + 2\gamma_{q2} x_{qi}) \Phi(\mathbf{x}_{1i} \boldsymbol{\beta}) \phi(\mathbf{x}_{2i} \boldsymbol{\gamma}) \exp\left(\mathbf{x}_3 \boldsymbol{\delta} + \frac{\sigma^2}{2}\right) \\ &+ (\delta_{q1} + 2\delta_{q2} x_{qi}) \Phi(\mathbf{x}_{1i} \boldsymbol{\beta}) \Phi(\mathbf{x}_{2i} \boldsymbol{\gamma}) \exp\left(\mathbf{x}_3 \boldsymbol{\delta} + \frac{\sigma^2}{2}\right) \end{aligned} \quad (10)$$

The marginal effect of a variable on other probabilities and expected values can be similarly derived.

One of the analytical benefits of using panel data is the ability to control for unobserved time invariant individual household characteristics. Typically, control for these unobserved household heterogeneities is done by employing fixed effects (FE) and random effects (RE) estimators. However, these traditional estimators have their own weaknesses. The RE models assume no correlation between unobserved heterogeneity and the observed explanatory variables in the model. If this RE assumption holds then cross-sectional analysis employing OLS estimation would also consistently estimate the model parameters (Wooldridge 2010). Although FE model is attractive in that it allows arbitrary correlation between the unobserved heterogeneity and the observed explanatory variables, its major weakness is that the transformation it uses to remove the unobserved heterogeneity also removes all time invariant explanatory variables and this can be problematic especially if a researcher would like to obtain estimates on time constant covariates (Burke and Jayne 2014; Muricho Geoffrey 2015).

The alternative method that provides the FE coefficients for time varying regressors is the correlated random effects (CRE) estimator. The CRE estimator, unlike fixed effects, also allows one to estimate how important the persistent components of the covariates are, and provides estimates for the effects of time-constant covariates. The various subsets of results allow us to interpret the effect of a covariate both from changes within a given household and from differences between two households (Burke and Jayne 2014).

In this paper, we use an approach that dates back to Mundlak (1978) and was extended by Chamberlain (1982, 1984). The so-called "Mundlak-Chamberlain device" is an example of a CRE estimator. Specifically, one models the relationship between the unobserved heterogeneity ψ_i and the observed explanatory variables. To construct the Mundlak-Chamberlain device, the average of time-variant regressors over time were computed from the two panel periods. These average timed variables were added in the first, second and third hurdle models as additional explanatory variables. This is modelled as follows.

Let X denote the $1 \times K$ set of all time-varying explanatory variables, excluding time invariant variables. For each cross-sectional observation i , let \bar{X}_{ij} be the $1 \times K$ vector time averages, with j th entry

$$\bar{X}_{ij} = T^{-1} \sum_{t=1}^T X_{itj} \tag{11}$$

Following Mundlak (1978), we assume a linear relationship between the unobserved heterogeneity ψ_i and the time averages, which can be written as:

$$\psi_i = \delta + \bar{X}_i \lambda + m_i \tag{12}$$

where δ is a scalar, \bar{X}_i is the averages of time varying explanatory variables, λ is a vector of coefficients to be estimated, and m_i is the error term which Mundlak (1978) assumed to have zero mean conditional on the entire history of the covariates $(X_{i1}, X_{i2}, \dots, X_{iT})$. In other words, the error term m_i is uncorrelated with X_{it} for all t and therefore \bar{X}_i . The model for the CRE analysis including the time constant variables will be as follows:

$$Y_{it} = \alpha_t^* + X_{it} \beta + \bar{X}_i \lambda + Z_i \gamma + m_i + \varepsilon_{it} \tag{13}$$

where the scalar δ is subsumed into the composite intercept term such that $\alpha_t^* = \alpha_t + \delta$, Y_{it} is the outcome variable and Z_i is a vector of time invariant explanatory variables. The idiosyncratic error term ε_{it} is assumed to be strictly exogenous, or uncorrelated with explanatory variables in all time periods. The β , λ and γ are parameters to be estimated. According to Schunck (2013) and Burke and Jayne (2014), β are interpreted as “within-household” effects. These “within-household” estimates are similar to the FE estimates meaning that these coefficients are the effect of a given time varying variable’s effect of deviation from its overall average or “permanent” level (Burke and Jayne 2014). These coefficients therefore, can simply be interpreted as the effect of a deviation within a given household. Conversely, λ and γ are interpreted as “between-household” effects, or the effect of a difference in the “permanent” levels of a variable between one household and another. For a detailed understanding on derivation and interpretation of “within” and “between” estimates, see Schunck (2013) and Burke and Jayne (2014).

4. Results and discussion

4.1 Descriptive statistics

Table 2 presents descriptive statistics of sampled households by adoption of ADP (adopters and non-adopters). For the whole sample, the average age of household heads was 47 years and 80% of households were male headed. Most of the household heads (58%) had only completed primary school education (seven years of formal education) while only 4% had completed some form of tertiary education. Turning to our descriptive statistics of interest, the results show that 13% of households owned trained oxen while 18% hired ADP for land preparation. Although only 3% of households owned rippers about 7% of households used MTR as a land preparation method (a statistic that confirms that adoption of MTR is low). Interestingly, 28% of households received CF advice; a result that demonstrates that a good number of farmers acquired some form of training but had not gone ahead to adopt the technology.

When we disaggregated the sample by adopters and non-adopters of ADP, we used the t -test to determine whether there is a statistically significant difference between the continuous variable means of the two groups. The chi-square test was used for categorical variables. The difference in means analysis for continuous variables (t -test analysis) revealed that relative to non-adopters, adopters had more labour available, cultivated more hectares of land, owned more livestock, lived closer to the camp office (government extension officers) but had less farm income. However, results for the difference in means statistics between adopters and non-adopters are

Table 2. Descriptive statistics of sampled households by adoption of animal draught power.

	Animal draught power						t-test and chi-square test
	Whole sample		Adopters		Non-adopters		
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	
<i>Farmer and farm characteristics</i>							
Labour availability (Adult equivalent)	4.99	2.26	5.25	2.41	4.79	2.12	-11.87**
Age (years)	47.62	14.76	47.34	14.65	47.82	14.84	-1.89
Gender of household head (=1 if male, 0 o/w)	0.80	0.40	0.82	0.38	0.79	0.41	29.89***
No education (=1 if yes, 0 o/w)	0.22	0.41	0.14	0.23	0.12	0.20	0.58
Primary education of head (=1 if yes, 0 o/w)	0.58	0.49	0.57	0.49	0.58	0.49	0.34
Secondary education of head (=1 if yes, 0 o/w)	0.26	0.44	0.26	0.44	0.26	0.44	0.38
Tertiary education of head (=1 if yes, 0 o/w)	0.04	0.19	0.03	0.18	0.04	0.19	5.82**
Hectares of land cultivated	2.48	2.55	3.40	3.17	1.82	1.70	-35.08***
Use of CF (=1, if yes, 0 o/w)	0.06	0.24	0.10	0.30	0.03	0.17	358.67***
Use ripping (=1, if yes, 0 o/w)	0.07	0.26	0.17	0.38	0.00	0.07	1400***
Own a ripper (=1, if yes, 0 o/w)	0.03	0.17	0.06	0.24	0.00	0.07	412.10***
Ownership of trained oxen (=1 if yes, 0 o/w)	0.13	0.33	0.28	0.45	0.01	0.12	2300***
Tropical livestock units	3.86	10.94	7.43	14.72	1.28	5.78	-30.62***
Hire ADP (=1, if yes, 0 o/w)	0.18	0.39	0.43	0.50	0.00	0.00	4400***
Net off farm income (kwacha)	6549.8	25,131	5884	20,022	7032	28,256	10.31**
Distance to nearest agro dealer (km)	1.44	1.73	1.42	1.42	1.45	1.92	1.11
Distance to nearest camp office (km)	0.84	1.31	0.78	1.12	0.88	1.43	4.88**
Distance to nearest Vet seller (km)	0.72	1.46	0.69	1.30	0.74	1.57	1.86
<i>Institutional factors</i>							
Receive CF advice (=1, if yes, 0 o/w)	0.28	0.45	0.31	0.46	0.27	0.44	29.73***
Loan access (=1, if yes, 0 o/w)	0.17	0.38	0.25	0.43	0.11	0.32	452.86***
<i>Locational factors</i>							
Central (=1, if yes, 0 o/w)	0.09	0.29	0.14	0.35	0.05	0.22	358.34***
Copperbelt (=1, if yes, 0 o/w)	0.07	0.26	0.03	0.17	0.11	0.31	307.28***
Eastern (=1, if yes, 0 o/w)	0.24	0.43	0.34	0.48	0.16	0.37	603.44***
Luapula (=1, if yes, 0 o/w)	0.10	0.29	0.00	0.04	0.16	0.37	1100***
Lusaka (=1, if yes, 0 o/w)	0.04	0.19	0.03	.181	0.04	0.20	5.50**
Muchinga (=1, if yes, 0 o/w)	0.07	0.26	0.01	.080	0.12	0.33	690.14***
Northern (=1, if yes, 0 o/w)	0.11	0.31	0.02	.149	0.17	0.38	799.32***
Northwestern (=1, if yes, 0 o/w)	0.07	0.26	0.01	0.09	0.12	0.32	628.65***
Southern (=1, if yes, 0 o/w)	0.12	.330	0.28	0.45	0.01	.114	2200***
Western (=1, if yes, 0 o/w)	0.08	.278	0.14	0.34	0.05	0.210	368.65***
Number of observations		14,213		5975		8238	

Notes: Mean differences between sub-samples tested by unequal-variance t-test for continuous variables. Pearson's chi-square test was used to test independence for categorical variables. Significance levels denoted as: ***=1%, **=5%.

Source: Authors' calculations based on Rural Agricultural Livelihoods Survey (2012 and 2015).

not statistically significant for the three variables – age of the household head, distance to nearest agro dealer and distance to nearest seller of veterinary products. This finding simply suggests that adopters and non-adopters were very similar in terms of age, distance to nearest agro dealer and distance to nearest seller of veterinary products. The chi-square test results showed that there is no significant difference between the two groups of adopters and non-adopters in terms of their levels of education. All other categorical variables are significant using the chi-square test.

Table 3 shows the descriptive statistics by adoption of MTR (adopters and non-adopters). Since the descriptive statistics for the whole sample are the same as what is presented in Table 2, we only focus our discussion on the difference in means reported in Table 3. Results of the t-test analysis show that compared to non-adopters, adopters of MTR had less labour available, were younger, cultivated more land, had more livestock, had less off-farm income and generally lived closer to agricultural service providers. The chi square test showed that there was a statistically significant difference between adopters and non-adopters for all categorical variables except for gender of the household head, the education dummy variables and provincial dummy for Lusaka province.

Table 3. Descriptive statistics of sampled households by adoption of minimum tillage ripping.

Variable name	Minimum tillage ripping						t-test and chi-square test
	Whole sample		Adopters		Non-adopters		
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	
<i>Farmer and farm characteristics</i>							
Labour availability (adult equivalent)	4.99	2.26	4.83	2.23	5.00	2.26	2.33***
Age of the household head (years)	47.62	14.76	44.72	14.44	47.85	14.76	6.78***
Gender of household head (=1, if male, 0 o/w)	0.80	0.40	0.82	0.39	0.80	0.40	0.13
No education (=1, if yes, 0 o/w)	0.22	0.41	0.13	0.34	0.12	0.23	0.58
Primary education (=1, if yes, 0 o/w)	0.58	0.49	0.57	0.50	0.58	0.49	0.44
Secondary education (=1, if yes, 0 o/w)	0.26	0.44	0.26	0.44	0.26	0.44	0.89
Tertiary education o (=1, if yes, 0 o/w)	0.04	0.19	0.04	0.19	0.04	0.19	0.75
Hectares of land cultivated	2.48	2.55	2.97	2.60	2.44	2.54	-6.38***
Own a ripper (=1, if yes, 0 o/w)	0.03	0.17	0.13	0.33	0.02	0.14	383.02***
Ownership of trained oxen (=1, if yes, 0 o/w)	0.13	0.33	0.19	0.39	0.12	0.33	46.59***
Tropical livestock units	3.86	10.94	4.10	11.36	3.84	10.91	-0.70***
Hire ADP (=1, if yes, 0 o/w)	0.18	.387	0.77	0.42	0.14	0.34	2700***
Net off farm income (Kwacha)	6549.8	25,131.5	5284	17,580.6	6652	25,642	12.44***
Distance to nearest agro dealer (km)	1.44	1.73	1.28	1.43	1.45	1.75	-4.54***
Distance to nearest camp office (km)	0.84	1.31	0.71	0.95	0.85	1.33	4.45***
Distance to nearest Vet seller (km)	0.72	1.46	0.89	1.28	0.70	1.48	3.59***
<i>Institutional factors</i>							
Receive CF advice (=1, if yes, 0 o/w)	0.28	0.45	0.40	0.49	0.28	0.45	75.72***
Loan access (=1, if yes, 0 o/w)	0.17	0.38	0.29	0.45	0.16	0.37	109.08***
<i>Locational factors</i>							
Central (=1, if yes, 0 o/w)	0.09	0.29	0.12	0.33	0.09	0.28	15.71***
Copperbelt (=1, if yes, 0 o/w)	0.07	0.26	0.04	0.19	0.08	0.27	23.76***
Eastern (=1, if yes, 0 o/w)	0.24	0.43	0.38	0.49	0.23	0.42	129.98***
Luapula (=1, if yes, 0 o/w)	0.10	0.29	0.01	0.08	0.10	0.30	105.02***
Lusaka (=1, if yes, 0 o/w)	0.04	0.19	0.04	0.21	0.04	0.19	1.05
Muchinga (=1, if yes, 0 o/w)	0.07	0.26	0.01	0.09	0.08	0.27	72.21***
Northern (=1, if yes, 0 o/w)	0.11	0.31	0.02	0.12	0.12	0.32	103.48***
Northwestern (=1, if yes, 0 o/w)	0.07	0.26	0.01	0.10	0.08	0.26	63.98***
Southern (=1, if yes, 0 o/w)	0.12	0.33	0.26	0.44	0.11	0.32	193.55***
Western (=1, if yes, 0 o/w)	0.08	0.28	0.11	0.32	0.08	0.27	12.24***
Number of observations	14,213		1063		13,150		

Notes: Mean differences between sub-samples tested by unequal-variance t-test for continuous variables. Pearson's chi-square test was used to test independence for categorical variables. Significance levels denoted as: ***=1%, **=5%.

Source: Authors' calculations based on Rural Agricultural Livelihoods Survey (2012 and 2015).

4.2 Econometric analysis

The econometric analysis for this paper was done in stages. First, the triple hurdle model was estimated from which the APEs were computed at stage 1 (adoption of ADP), stage 2 (adoption of MTR conditional on adopting ADP) and stage 3 (number of hectares ripped conditional on adopting ADP and MTR). Second, the CRE estimator was applied to the data to estimate unconditional APEs. The unconditional APEs measure the effect of a given determinant on the expected value of hectares ripped, not conditional on using ADP or MTR. The CRE produces the within- and between-household effects of results which allow us to interpret the APEs on the expected value of hectares ripped across time but within the same household (within-household effect) and across households at a given time (between-household effect).

4.2.1 Average partial effects for ADP adoption, MTR adoption and intensity of ripping

Table 4 shows results of the triple hurdle model. Column (i) reports the conditional APEs of ADP adoption, column (ii) reports the conditional APEs of MTR adoption, and column (iii) presents the conditional APEs of hectares ripped. The standard errors are reported in parenthesis and the significance levels denoted by asterisks.

Results indicate that male-headed households were 2.3 percentage points more likely to use ADP, on average, than female-headed households and this is statistically significant at 1%. Similar results

Table 4. Determinants of adoption of animal draught power, minimum tillage ripping and intensity of ripping.

Variables	ADP (i)	MTR (ii)	Ha under ripping (iii)
<i>Farmer and farm characteristics</i>			
Gender (1 = male)	0.023*** (0.008)	0.005 (0.013)	0.114* (0.063)
Labour availability	0.003** (0.002)	-0.010*** (0.002)	0.004 (0.012)
Age of head	-0.002* (0.001)	-0.004* (0.002)	0.005 (0.010)
Age squared	0.000 (0.000)	0.000 (0.000)	-0.000 (0.000)
Primary education	-0.018** (0.009)	-0.000 (0.015)	-0.137* (0.071)
Secondary education	-0.027** (0.010)	-0.005 (0.017)	-0.062 (0.080)
Tertiary education	-0.032* (0.019)	0.030 (0.029)	-0.054 (0.134)
Hectares cultivated	0.039*** (0.002)	-0.006*** (0.002)	0.223*** (0.010)
Ownership of a ripper	0.132*** (0.022)	0.204*** (0.017)	-0.005 (0.079)
Tropical livestock units		-0.004*** (0.001)	-0.048 (0.079)
<i>Institutional factors</i>			
Distance to vet seller	-0.010*** (0.002)	0.019*** (0.004)	0.035 (0.022)
Distance to agro dealer	-0.003 (0.002)	-0.014*** (0.004)	0.003 (0.020)
Distance to agric camp office	-0.000 (0.003)	-0.007 (0.005)	-0.048* (0.028)
CF advice	-0.011 (0.007)	0.037*** (0.011)	0.226*** (0.050)
Fertiliser price per kg	0.003 (0.003)	0.009** (0.004)	0.014 (0.023)
Loan access	0.014* (0.008)	0.022* (0.012)	0.028 (0.054)
Joint provincial dummy	17693***	34.02***	3.99***
Log likelihood	-5401.7	-2516.1	
F-test			27.85***
Number of observations	14213	5975	1063

Notes: Probit model results for ADP and ripping adoption and Lognormal model results for Ha ripped. APEs with standard errors in parenthesis; ***, **, * Significant at 1%, 5%, and 10% respectively. The variable tropical livestock units was not included in the first hurdle of adoption of ADP but included in the last two hurdles of adoption of ripping and intensity of ripping respectively. Source: Authors' calculations based on Rural Agricultural Livelihoods Survey (2012 and 2015).

were found by Chimonyo et al. (1999) indicating that use of ADP by female headed households was limited. The reason for this is that male headed households are generally better endowed with resources required for ADP adoption given the patriarchal nature of farming communities in sub-Saharan Africa. Results further indicated that a one-unit increase in labour availability, proxied by the adult equivalent measure, was associated with an increase in the likelihood of adoption of ADP by 0.3 percentage points. This is in line with the findings by Savadogo, Thomas, and Pietola (1998), who found that size of the household was positively related with adoption of animal traction technology.

Results also show that with an increase in age of the household head, the likelihood of adopting ADP reduced by 0.2% but this finding is statistically significant at only 10% level. This implies that older farmers are less likely to use animal traction technology probably because their physical ability to participate actively in farming activities declines with increasing age. We included the variable age squared (computed by squaring the age for each household head in our sample) in the triple hurdle model to test for a non-linear relationship between age and the dependent variable

at each stage of our estimation. Our results reject the null hypothesis that there is a non-linear relationship between age and the dependent variables in our triple hurdle model.

The three categories of education were all found to be significant in influencing adoption of ADP. Those that attained primary education were 1.8 percentage points less likely to adopt ADP on average, compared to those with no education. Those that attained secondary and tertiary education were 2.7 and 3.2 percentage points less likely to adopt ADP on average compared to those that had no education, respectively. This may be because most educated farmers do not depend solely on farming activities and do other activities such as businesses and formal employment in order to earn an income. It was observed that the likelihood of adoption reduced as the education level increased. An increase in the hectares cultivated, which was used to measure the productiveness of the farmer, by one unit increased the likelihood of adoption of ADP by 3.9 percentage points on average. This could be due to the fact that farmers who make maximum use of their land are more organised and willing to take up risks and new technology. The more hectares cultivated, the more the need to reduce manual labour cost through the use of ADP. Similar results concerning land were found by Makki, Eltayeb, and Badri (2017) indicating that ADP adoption is positively driven by farm size.

Ownership of a ripper increased adoption of ADP by about 13.2 percentage points on average and this is statistically significant at 1% significance level. On average, increase in the distance to the nearest seller of veterinary products reduced adoption of ADP by 1 percentage point and this is significant at 1% significance level. The distances to the nearest agro dealer and to the nearest seller of veterinary products had a negative relationship to the adoption of ADP but this is not statistically significant for both. Moreover, access to loans increased the likelihood of adoption of ADP by 1.4 percentage points, on average. These results are similar to those found by Mbata James (2001), who found that access to credit was positively related with adoption of ADP and Makki, Eltayeb, and Badri (2017) who recommended the need for access to credit as a driver to increase adoption of animal traction. The joint test for the provincial dummies indicated that there were significant differences in the adoption of ADP in the different provinces and this is significant at 1% significance level.

Results from the second stage of the triple hurdle model (adoption of MTR conditional on ADP adoption) indicate that increase in labour by one unit reduced the likelihood of MTR adoption by 1 percentage point and this is statistically significant at 1%. This may be because households that use ripping do not require much labour compared to those that do not use ripping. Increase in age of the household head by one year reduced the likelihood of adopting MTR by 0.4 percentage points on average and this is statistically significant at 10% significance level. This is as expected because the older the household head, the less willing they will be to try new technologies. Increase in hectares cultivated by one hectare reduced the likelihood of adopting ripping by 0.6 percentage points and this is statistically significant at 1%.

Increase in the number of rippers owned increased the likelihood of MTR adoption, on average, by 20.4 percentage points and this is significant at 1% significance level. Increase in livestock units reduced the likelihood of MTR adoption by 0.4 percentage points on average and this result is statistically significant at 1% significance level. An increase in the distance to the nearest seller of veterinary products increased the likelihood of MTR adoption by 1.9 percentage points on average, statistically significant at 1% significance level. It is expected that the further away the seller of veterinary products is, the less likely that farmers will adopt the technology. Our results demonstrate that this is not the case. This may be because farmers still adopt ripping using ADP, irrespective of the distance to the nearest seller of veterinary products.

Our a priori expectation was that an increase in the distance to the nearest agro dealer would reduce the likelihood of MTR adoption. Our results confirm this expectation as shown by statistically significant effect of a 1.4 percentage points increase in the likelihood of adopting MTR. As expected, households that received advice on CF were more likely to adopt MTR. This is expected as CF advice dissemination enhances awareness of the technology which in turn increases the likelihood of adoption. A surprising result was the APE of the price of fertiliser per kg. Results show that the price of

fertiliser had a positive and significant relationship with MTR adoption. This suggests that when farmers are faced with a decision between MTR and alternative technologies, the likelihood of adopting MTR is enhanced (in part because of the perceived benefits of the technology) when price of fertiliser per kg increases by a unit. Similar to ADP adoption, access to loans increased the likelihood of adopting MTR by 2.2 percentage points on average, a result that is statistically significant at 10%. The provincial dummies showed that there were some significant differences in the adoption of ripping by farmers across the different provinces.

Results of the third stage of the triple hurdle model indicate that relative to women headed households, male headed households were expected to increase the number hectares under ripping by 0.114 hectares. Compared to those with no education, household heads that attained primary education were associated with a reduction in the number of hectares under ripping by 0.137 hectares. Increase in hectares cultivated increased the area under ripping by 0.223 hectares, on average, and this result is statistically significant at 1%. Another important determinant of hectares under ripping was distance to the nearest agriculture camp office which was negatively associated with the former. Households receiving CF advice were, on average, likely to experience an increase in the area under ripping by 0.226 hectares.

4.2.2 Unconditional average partial effects of the CRE estimator

As explained in previous sections, the unconditional APEs estimated using CRE estimator measure the effect of a given determinant on the expected value of hectares under ripping, not conditional on adopting ADP and MTR. After running the triple hurdle model in Stata 14, the inverse Mills ratio (IMR1) was generated to test the null hypothesis that the errors between stage one and two were conditionally uncorrelated. The IMR was not significant as demonstrated by a p -value of 0.37. Therefore, IMR1 was not included in the second stage as an additional regressor. The same process was repeated in the second stage where the inverse Mills ratio (we call it IMR2 to differentiate it from the stage 1 IMR1) was generated. The generated IMR2 was not significant with a p -value of 0.55 and therefore not included in the third stage.

APEs were computed manually for the unconditional expected value of the area under ripping and results of the CRE are as shown in Table 5, disentangled as within-household and between-household effects allowing for a more nuanced understanding of how determinants explain variation in the outcome. A joint test was done on the time averaged variables used to construct the Mundlak-Chamberlain device and the chi-square test statistic was $\chi^2_{(44)} = 352.77$, which was statistically significant at 1%. This means that the null hypothesis that these time averaged variables are jointly equal to zero was strongly rejected (Wooldridge 2010). This test for the Mundlak-Chamberlain device variables implies that the unobserved heterogeneity is significantly correlated with the observed explanatory variables in the model (Burke and Jayne 2014).

When we consider age of the household head, results indicate that the variable has a highly significant negative relationship with the expected value of hectares ripped based on the within-household APE. The results suggest that an increase in household head age by one year was associated with a reduction in the expected value of hectares ripped of 0.54 hectares. The between-household effect, on the other hand, shows a positive effect of household head age on the expected value of hectares ripped. All else constant, a household that is older by a year was more likely to increase the hectares ripped by 0.7 hectares, than a similar household that is younger.

The between-household effect results suggest that households with more land under cultivation were expected to rip a smaller number of hectares on average compared to similar households with less land under cultivation. However, the within-household effect APEs show that an increase in the hectares cultivated by one hectare increased the expected value of hectares ripped by 2.1 hectares for a household, all else constant. This means that as the farm for the household grows overtime, more land is likely to be allocated to ripping.

Education was specified as a categorical variable with four groups: (1) no formal education (base category); (2) primary education; (3) secondary education and; (4) tertiary education. Results of the

Table 5. Unconditional average partial effect (APE) estimates of the expected value of hectares ripped.

Explanatory variables for hectares ripped	CRE estimator	
	Within-hh effect (i)	Between-hh effect (ii)
Age of the household head	-0.54*** (0.00)	0.70*** (0.00)
Hectares cultivated	2.06*** (0.00)	-0.91*** (0.00)
Primary	0.43*** (0.00)	-1.06*** (0.00)
Secondary	1.79*** (0.00)	-1.82*** (0.00)
Tertiary	4.85*** (0.00)	-2.90 *** (0.00)
Labour availability	-1.37 *** (0.00)	1.19*** (0.00)
Gender (1 = male)	3.55*** (0.00)	-2.33*** (0.00)
Own a ripper	10.61*** (0.00)	2.04*** (0.00)
Tropical livestock units	-0.27*** (0.00)	3.86 *** (0.00)
Distance to nearest agro dealer	-0.86*** (0.00)	1.18*** (0.00)
Distance to nearest vet seller	2.25*** (0.00)	-3.75*** (0.00)
Distance to nearest camp office	-0.65*** (0.00)	0.18*** (0.00)
CF advice	4.84*** (0.00)	-7.95*** (0.00)
Loan access	0.098*** (0.00)	1.97 *** (0.00)
Price of fertiliser per kg	1.99*** (0.00)	-2.24*** (0.00)

Notes: Unconditional APEs with Delta-method *p*-values in parentheses; *** Significant at 1%.

Source: Authors' calculations based on Rural Agricultural Livelihoods Survey (2012 and 2015).

within-household effects show that compared to the initial condition of no formal education, a household head with primary or secondary or tertiary education was expected to have more hectares ripped. This implies that as households become more educated overtime, they understand and realise the importance of ripping and increase the hectares ripped. The between-household effects show that, holding all factors constant, a household that has a higher level of education was expected to rip a relatively smaller number of hectares compared to a household with no education.

Labour availability showed a negative relationship with the expected number of hectares ripped for the within-household effects. Results show that an increase in labour availability by one unit was associated with a reduction in the expected number of hectares ripped of 1.4 hectares for a given household. However, the between-household effects results show that increasing labour in a household by one unit relative to a similar household increased the number of hectares ripped by 1.2 hectares.

Regarding the effect of gender of the household head on the within-household effect of hectares ripped, results show that a male-headed household was likely to increase the number of hectares ripped by 3.5 hectares compared to the case if the household was female-headed. The between-household effect results show that a male-headed household would likely reduce the number of hectares ripped by 2.3 hectares compared to a similar household but that is female headed. Ownership of a ripper increased the unconditional expected value of hectares ripped by 10.1 hectares for the within household effect analysis. The between-household effect results also show a positive result that suggests that ownership of a ripper would likely increase the number of hectares ripped relative to a household that does not own a ripper, holding all things constant.

The total livestock units (TLU) estimates for the within-household effects were negative suggesting that an increase in TLU in a household by one unit reduced the number of hectares under ripping by 0.27 hectares. Across households with similar characteristics, increasing the number of livestock units was associated with an increase in the number of hectares ripped by 3.86. This shows that farmers with more livestock are probably more involved in ripping as they can divide their livestock across many farming activities.

The distance to the nearest agro-dealer and that to the agriculture camp office had negative APEs on hectares ripped for within-household effects. On the other hand, the between-household effects showed that increase in the distance to the nearest agro dealer and agriculture camp office increased the hectares ripped by 1.2 and 0.2 hectares respectively. The distance to the nearest seller of veterinary products showed a positive within effect with a value of 2.2. A household further away from a seller of veterinary products was expected to reduce the number of hectares ripped by 3.7 hectares compared with a similar household closer to the service provider. Farmers get veterinary drugs for the animals used in ripping. Therefore, the further the veterinary products seller, the less accessible the drugs needed for the animals used in ripping.

Increased access to CF advice increased the within-household effect on hectares ripped of 4.8 hectares. Overtime as the conservation farming advice increases, a given household is expected to follow this advice and thus increase the hectares ripped. The between-household effect showed that a household that received CF advice was less likely to increase the hectares ripped compared to a similar household that did not receive CF advice.

Increased access to loans was associated with an increase of 0.1 and 1.97 hectares for the within- and between-household effects respectively. This makes sense as loans create incentives for the farmers to take up risks and invest in new technology. Increase in the price of fertiliser per kg by one unit was likely to increase the hectares ripped by 2 hectares for the within-household effects. The between-household effect results show that an increase in price of fertiliser had a negative effect on the hectares ripped of 2.2 hectares. Increase in input prices affect the decision of how many hectares should be ripped for households. As these prices increase, farming becomes costlier and the farmer responds by reducing the hectares ripped, all else constant.

5. Conclusion and policy implications

The objective of this study was to explore the factors that determine adoption of minimum tillage ox-drawn ripping (one of the agronomic practices of conservation farming) among smallholder farmers using the case of Zambia. Given the fact that conservation farming is touted to be an important agricultural technology with potential to significantly increase farmers' production and productivity, understanding the determinants associated with adopting the technology is crucial for designing effective policies for scaling up its promotion. To unpack the determinants of adopting MTR, we used the triple hurdle approach to first estimate APEs of ADP adoption (stage 1) after which APEs of MTR adoption conditional on ADP adoption were estimated at stage 2. The third stage involved estimation of APEs of the number of hectares ripped conditional on ADP and MTR adoption. In addition, the CRE estimator was applied to the data to estimate the unconditional average partial effects (APEs) on the expected value of hectares ripped.

The following key findings emerged from our analysis of the triple hurdle model estimates. The factors that had a positive influence on ADP adoption included labour availability proxied by the number of adult equivalent units, the dummy variable for male household heads, number of hectares cultivated, ownership of rippers and loan access. On the other hand, our results suggest that age of the household head, completion of different levels of formal education (primary, secondary and tertiary) relative to no formal education and distance to the nearest seller of veterinary products all had a negative effect on adoption of ADP. Coming to adoption of MTR conditional on ADP adoption, our findings suggest that male headed households were more likely to adopt ripping compared to female headed households. Other factors that positively influenced adoption of MTR were

ownership of a ripper, distance to the nearest seller of veterinary products, receiving advice on CF, price of fertiliser per kg and loan access. Our examination of factors that determine the number of hectares ripped conditional on ADP and MTR adoption show that male headed households were more likely to increase the hectares under ripping compared to their female counterparts. In addition, increasing the number of hectares cultivated and receiving CF advice were associated with an increase in the number of hectares under ripping. However, household heads that had primary education were less likely to increase hectares under ripping compared to those with no education.

Our analysis of the unconditional APEs of the CRE estimator point to a number of interesting findings. First, all the independent variables included in this approach were statistically significant at 1% significance level. Second, the within- and between-household effects reported by the CRE showed opposite effects apart from ownership of a ripper and loan access that showed positive signs for both effects. The CRE results demonstrate that while certain factors enhance or inhibit the expected value of hectares ripped within a given household, it is not always the case that the said factors have a similar effect when the analysis is between households.

Put together, our findings of the triple hurdle model and the CRE estimator point to the following policy implications. First, the positive association between ownership of rippers and adoption points to the importance of creating incentives that would enhance ownership of rippers by smallholder farmers. Second, the fact that loan access is positively associated with a higher likelihood of adopting ADP also calls for policy strategies that support improved access to loans for farmers. Third, the explanatory power of distance to sellers of veterinary products and services confirms the importance of promoting agro-dealer networks that are located closer to farmers. Fourth, our findings also support intensified dissemination of CF advice as a strategy for increasing MTR adoption and the number of hectares allocated to ripping conditional on ADP adoption. These strategies for CF advice dissemination should be innovative to help enhance adoption.

Note

1. In this paper, conservation agriculture and conservation farming are used interchangeably.

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