



Wealth-related inequalities in adoption of drought-tolerant maize and conservation agriculture in Zimbabwe

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Abstract

This paper concerns Drought-Tolerant Maize (DTM) and Conservation Agriculture (CA) practices that were introduced into smallholder maize-based farming systems in Zimbabwe to enhance the productivity of maize and food security under a changing climate. Although these technologies are technically appropriate, there are difficulties with their use by smallholder farmers of relatively low socio-economic status, as measured through ownership of farm or household assets and endowments. Thus, we sought to quantify and explain wealth-related inequalities in the adoption of DTM and CA in smallholder farming communities and discuss their implications for food security. The analysis used cross-sectional household-level data gathered from 601 smallholder farmers from four districts in Zimbabwe. We found evidence of a pro-rich distribution of inequalities in the adoption of DTM and CA that were mostly explained by differences in household wealth, access to agricultural extension services and size of farm land. No meaningful differences in DTM adoption disparities were found across districts. Significant gender differences were observed for CA, and meaningful differences by district were noted. Results suggest the need for decision makers to consider implementing policies that focus on the poorer segments of the farming society to alleviate differences in the adoption of such agricultural technologies. For example, subsidizing the uptake of improved maize varieties including DTM and prioritizing equitable land distribution, coupled with specialised extension services for the poor in a cereal-based CA farming system, could reduce the observed gap between rich and poor in the uptake of these innovations and consequently improve food security.

Keywords Climate-smart agriculture · Food security · Socioeconomic inequalities · Smallholder farmers · Concentration index · Zimbabwe

1 Introduction

Significant investment in agricultural production practices (technologies and methods) that improve farmers' food security and resilience against weather-related shocks (such as droughts), is a key strategy that can mitigate the associated adverse impacts (Cairns et al. 2013; Davies et al. 2009; Katengeza et al. 2016; Makate et al. 2017; Pangapanga et al. 2012). Maize is one significant crop in sub-Saharan Africa (SSA), including Zimbabwe, that has been targeted by programs aiming to enhance climate resilience and food security in smallholder farming systems (Fisher et al. 2015; Fisher and Carr 2015; Makate et al. 2017). The maize crop is at risk due to persistent weather shocks that are evident in some parts of SSA (Fisher and Carr 2015; CIMMYT 2013), yet it is a very important staple crop for food security in the region (Mango et al. 2017; Mango et al. 2014; Nyikahadzo et al. 2012). In Zimbabwe, maize is the most important cereal crop, vital for food security, with the average per capita per day consumption

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estimated to be 248 g of grain (Ranum et al. 2014). Zimbabwe recorded at least 20 drought episodes, as measured by the standardized precipitation index between 1900 and 2013 (Masih et al. 2014), which highlights the level of climate risk.

Drought-Tolerant Maize (DTM) – a ‘climate-smart’ agricultural technology now widely available in Africa – is expected to improve resilience of maize-based farming systems in Zimbabwe, thereby enhancing food security and nutrition (Fisher et al. 2015; Makate et al. 2017) as well as alleviating poverty (Abdoulaye et al. 2018; Jaleta et al. 2018; Lunduka et al. 2017; Wossen et al. 2017). Evidence from Zimbabwe suggests that smallholder farmers who adopt DTM varieties are more likely to be food secure for an extended period of time and are also expected to have additional income to boost their food security prospects (Lunduka et al. 2017). A recent study in Ethiopia also showed that in the absence of DTM adoption, expenditure on food consumption of an ordinary household was expected to decline by an estimated US\$119 per year while food insecurity increased by about 2.5 percentage points (Jaleta et al. 2018). In addition, DTM varieties have high protein content in their grain and stronger resistance to major diseases (Fisher et al. 2015). DTM has been promoted in Africa in the last decade through the Drought Tolerant Maize for Africa (DTMA) project, launched in 2006 and implemented in 13 countries across SSA. The primary purpose of that project was to increase household food security and income of smallholder farmers through the development and dissemination of drought tolerant, well-adapted maize varieties. The project was jointly implemented with National Agricultural Research Services by the International Maize and Wheat Improvement Center (CIMMYT) in eastern and Southern Africa and the International Institute for Tropical Agriculture (IITA) in western Africa (Lybbert and Carter 2015) and ended in 2015 (Lunduka et al. 2017). Zimbabwe is one of the countries where successful trials on selected farms were conducted followed by widespread promotion and adoption programs (Kassie et al. 2012).

Conservation Agriculture (CA) is another ‘climate-smart’ agricultural practice strongly promoted to improve climate resilience and productivity of the maize crop (Baudron et al. 2012; Thierfelder et al. 2017; Thierfelder and Wall 2010) while conserving the environment in SSA countries including Zimbabwe (Mango et al. 2017). CA can also improve crop diversification and soil quality – important factors associated with food security. CA was promoted after observing that frequent droughts severely threaten the food security situation of many smallholder agriculture-based communities in southern Africa, which are characterised by low crop productivity, food insecurity, hunger and malnutrition (Mango et al. 2017; Nyikahadzoi et al. 2012). These communities experience problems of inadequate farming knowledge and skills, insufficient implements and inputs such as seeds, fertilizers, herbicides and pesticides, along with poor soils and soil fertility

management. CA involves minimum soil disturbance, permanent soil cover, and crop rotations that give rise to suites of practices. Mulching and reduced tillage are the ones commonly employed in SSA, including Zimbabwe (Giller et al. 2009; Siziba 2008). The Food and Agricultural Organization of the United Nations (FAO), government ministries, non-governmental organizations and national and international research institutes have all been making concerted efforts to promote CA in southern Africa since the mid-1980s (FAO 2001).

There is now substantial information on the main determinants of adoption of DTM and CA. Research on DTM adoption reports that numerous socioeconomic characteristics of farmers (including access to information, resource endowments and gender) explain variation in adoption (Fisher et al. 2015; Fisher and Carr 2015; Holden and Fisher 2015; Holden and Quiggin 2016; Makate et al. 2017). Similarly, literature on CA adoption demonstrates that different socioeconomic and institutional factors also determine adoption of CA. Previous research has shown the importance of household wealth on DTM adoption (Legese et al. 2009) and found a somewhat pro-rich technology adoption gradient (DeWalt 1975; Lansing and Markiewicz 2011). These studies underline that smallholder farmers are not homogenous (Chikowo et al. 2014; Giller et al. 2011; Tiftonell et al. 2010) and that different farmer socioeconomic characteristics influence adoption of farming technologies (Asfaw and Admassie 2004; Fisher and Carr 2015; Mahapatra and Mitchell 2001; Milán et al. 2006; Solano et al. 2001; Somda et al. 2005). According to Fisher and Carr (2015), ensuring that DTM seed varieties meet the diverse needs of farmers is one crucial challenge still to be critically scrutinized and considered. Also, Thierfelder et al. (2012) stressed that both farm and community-level socioeconomic constraints to the adoption of CA (including rotations and intercropping) should be addressed in order to increase uptake.

Despite the strong links of DTM and CA to food security and human nutrition, the adoption of such strategies is still impeded by differences in household socioeconomic status, e.g., wealth endowments such as household assets (Fisher et al. 2015; Fisher and Carr 2015; Holden and Fisher 2015; Holden and Quiggin 2016; Makate et al. 2017). Input acquisition costs or prices have a major influence on the adoption of DTM and CA (Fisher et al. 2015). In the study we report here, we focussed on the wealth endowments of the household as an important factor in the adoption of such strategies. This was premised on the observation that a household’s wealth endowments could be an important predictor of their likelihood or ability to pay for agricultural inputs, including seed of DTM varieties.

Against this background, our study sought to quantify and decompose observed inequalities in DTM and CA adoption into their underlying determinants, using cross-sectional

household-level data from selected smallholder farming communities in Zimbabwe and derive implications for food security. Specifically, we measured and explain socioeconomic status-related inequalities in the adoption of DTM and CA using rank-based techniques, including the concentration index (see O'Donnell et al. (2008)). A subsequent decomposition of the observed disparities in adoption was performed to establish the underlying drivers of such inequalities. To the best of our knowledge, no study in low-income nations such as Zimbabwe has attempted to explain the inequalities related to socioeconomic status in the adoption of DTM and CA.

The rest of the article is organised as follows: section 2 discusses the study methodology and underlying empirical model and analytical framework; results of the study are presented in section 3 followed by discussion of the study findings in section 4. Conclusions and recommendations are in section 5.

2 Methods

2.1 Data

This study used cross-sectional household-level data collected during a survey conducted from October to December 2011 in four districts of Zimbabwe; Goromonzi, Guruve, Mudzi, and Hwedza. Goromonzi and Guruve districts fall in natural farming region IIb (sub-humid) while Hwedza and Mudzi are in regions III and IV (semi-arid), respectively. The study relied on data from districts with different agro-ecological zones since research has shown that DTM varieties (mainly hybrids) are important for all farmers and can outperform conventional maize varieties even in good rainfall situations (CIMMYT 2017). The four districts were selected based on agro-ecological potential and market access. Goromonzi and Guruve districts lie in agro-ecological zones of high potential, while Mudzi and Hwedza are in low potential zones. Mudzi has the lowest access to markets compared to the other three action sites. A simple random sampling technique was used to select wards from a list obtained from the district extension office of each of the four districts. Within the selected wards, the households selected for interview were randomly chosen from lists provided by resident agricultural extension officers. Using data from the 2002 Zimbabwe population census, Goromonzi, Mudzi, Hwedza, and Guruve had populations of 154,262, 128,174, 70,677 and 111,398 persons, respectively (Zimbabwe National Statistics Agency 2017). Population proportions generated from the district populations were used to generate the total study population. This stratification based on agro-ecological potential and market access generated a large sample from which 601 households were extracted for the survey; 175 from Goromonzi, 187 from Guruve, 120 from Mudzi and 119 from Hwedza.

Data collection was through face-to-face administration of structured questionnaires with the farmers. In the surveys, we collected information on household characteristics, including ownership and number of assets kept by the household, crop and animal production, access to agricultural extension services, agricultural inputs and technologies and the use of farming methods such as CA. Extensive data on asset holdings was collected which included information on ownership of live-stock, household goods (e.g., television, radio, bicycle), farm implements and other intermediate technologies (e.g., oxcart, planter, wheelbarrow, tractor, plough), household dwelling characteristics (such as floor, roof and wall material) and other common assets (such as mobile phones). The study used the information to generate a wealth index variable for the household using Principal Components Analysis (PCA). Crop production data included information on several crops, including maize. Detailed maize production information was collected and this included input use in production, land area for growing maize, hybrid maize seed varieties sown, crop management practices, harvesting methods, and post-harvest handling of the maize crop. Data on maize hybrid varieties also captured the adoption and use of DTM varieties. Specific questions were asked on whether a farmer planted any DTM variety, the amount of DTM seed sown, total output, and amount of output sold and consumed locally.

2.2 Outcome variables

In this study we used two binary measures of 'adoption' of two 'climate-smart' agricultural practices, DTM and CA¹ adoption. DTM² adoption was measured as a binary variable indicator taking 1, if the smallholder farmer had planted at least one of the released DTM varieties, and 0 otherwise. Several DTM varieties had been released at the time of the survey (see Abate et al. (2015)). CA was also measured as a binary indicator variable taking 1 if the farmer was practising at least one of the several practices that fall under CA and 0 otherwise.

2.3 Explanatory variables

Several explanatory variables that were believed to possibly explain adoption and contributions to observed inequalities in adoption of DTM and CA were included in the survey. These variables were age of household head, gender of household head, marital status of household head, labour, education of household head, extension, distance to the nearest main market, land size, asset wealth and region. The choice of these

¹ A farmer was considered a CA adopter if he or she had practiced any of reduced tillage, mulching, crop residue retention or crop rotations (in isolation or in combination) consistently in the last two seasons.

² A farmer was considered a DTM adopter if he or she reported planting at least one DTM hybrid or variety consistently in the two preceding seasons.

variables was guided by the empirical literature on adoption of CA and DTM. This work included Feder et al. (1985), Fisher et al. (2015), Fisher and Carr (2015), Fisher and Kandiwa (2014), Legese et al. (2009), and Makate et al. (2017) for DTM adoption, and Mazvimavi and Twomlow (2009), Nkala et al. (2011) and Siziba (2008) for CA adoption. Household head characteristics such as age, gender, marital status and education may influence the level of risk that can be tolerated, decision-making on the farm, access to resources, technology adoption, and the capacity to evaluate technologies and hence, they can explain wealth related disparities in the adoption of CA and DTM. The availability of labour also influences adoption of innovations on-farm (Murray et al. 2016) and access to extension affects access to information (Makate et al. 2018). Such variables may influence the accumulation of capital and resources and hence can explain wealth related disparities in technology adoption on-farm. In addition, distance to the nearest market may influence market access and rewards from the market (Fischer and Qaim 2014), while land size may influence technology adoption and hence rewards from farming (Bidogezza et al. 2009). Therefore, land size and distance to market may influence the wealth gradient in technology adoption on the farm. Regional variables capture variation in several characteristics intrinsic to a particular location, which can also explain a wealth gradient in technology adoption. Also, wealth itself is a known determinant of adoption of innovative technologies including CA and DTM (Legese et al. 2009; Makate et al. 2017; Mazvimavi and Twomlow 2009; Nkala et al. 2011) which means wealth can be an important factor in explaining inequalities in technology adoption on the farm. Specific details on measurement of all the explanatory variables, including their descriptive statistics, are shown in Tables 1 and 2.

2.4 Measuring socioeconomic status using an asset-based index

Studies in low-income countries are increasingly using asset-based indices as measures of the socioeconomic status of the family given the difficulty associated with acquiring data on household income or consumption (O'donnell et al. 2008). Our study followed this trend to compute the asset index as a proxy for household wealth using PCA (Filmer and Pritchett 2001). Several studies focusing on explaining disparities in health outcomes in low-income countries have used the asset index as a measure of socioeconomic status (Makate and Makate 2017; Gwatkin et al. 2007; Hajizadeh et al. 2014). This asset index is based on the household's ownership of key items of household property, livestock, and housing quality characteristics, and is summarized in Table 1. For brevity, the outputs from PCA are omitted and only the means of the variables are considered. The means of variables considered are shown by wealth category in Table 1.

2.5 Enumerating socioeconomic status (SES) related disparities in DTM and CA adoption

The concept of quantifying socioeconomic-related disparities in an outcome variable has received increased consideration in economics literature, especially papers dealing with health economics (Wagstaff et al. 2003; van Doorslaer et al. 1997; Kakwani et al. 1997; Wagstaff et al. 1991). Many studies have relied on inequality measures such as the Gini coefficient, relative index of inequality, relative index of dissimilarity and the concentration index (Wagstaff et al. 1991). Our study followed recent studies in health economics that employ concentration indices to measure disparities in health outcome variables. The outcome variables considered were binary and measure adoption of DTM and CA. Following Wagstaff et al. (2003), the standard concentration index can be specified as follows:

$$CI = \frac{2}{N\mu} \sum_{i=1}^n Y_i R_i - 1 - \frac{1}{N} \quad (1)$$

where Y_i represents the outcome variables for DTM and CA adoption for the i^{th} smallholder farmer, μ represents the mean for the dependent variables, and $R_i = 1/N$ is the rank of the smallholder farmer in the socioeconomic status distribution, with $i = 1$ representing the lowest ranked farmer (i.e. the poorest) and $i = N$ for the highly-ranked smallholder farmer (i.e. wealthiest). The CI is often written in a more convenient way as follows:

$$CI(Y) = \frac{2}{\mu} Cov(Y, R) \quad (2)$$

Note that equation (2) shows that the $CI(Y)$ depends only on the covariance between the outcome variable and the smallholder farmer's rank in the SES distribution and not on the measure of SES itself. The sign of $CI(Y)$ represents the direction of concentration of the index with the index ranging from -1 to $+1$. The index takes a value of zero if DTM and CA adoption rates are equally distributed in the population (i.e. no disparities related to socioeconomic status). A value of -1 implies that disparities in DTM or CA adoption are concentrated with the poor farmers (i.e. pro-poor) while a $+1$ indicates that DTM and CA adoption is all concentrated among the richest smallholder farmers (i.e. pro-rich).

As noted in Wagstaff (2005), in the case of a binary outcome variable, the computed concentration index might not only exceed the -1 and $+1$ boundaries, but also violate key properties such as the "mirror property". In the case of this study, the mirror property states that inequalities in adoption should mirror those in no adoption. In other words, we should expect to get the same magnitudes when our outcome variable is either measuring adoption of DTM or non-DTM with the only difference being in the sign. Thus, we used the corrected concentration index as suggested by Erreygers (2009), which

Table 1 Principal components and summary statistics for the variables used to compute the wealth index of a smallholder farmer in Zimbabwe

Variables	Overall			Quintile 1		Quintile 2		Quintile 3		Quintile 4		Quintile 5	
	Mean	SD	Component score	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Number of cattle	2.41	3.42	0.24	0.75	1.58	1.42	2.14	1.18	1.85	2.69	2.84	6.03	4.65
Owens draft cattle	0.50	0.50	0.22	0.13	0.34	0.48	0.50	0.35	0.48	0.63	0.49	0.90	0.30
Owens draft donkey	0.03	0.16	0.06	0.00	0.00	0.01	0.09	0.03	0.18	0.03	0.16	0.06	0.24
Owens sheep	0.19	1.05	0.07	0.04	0.27	0.09	0.49	0.03	0.22	0.23	1.21	0.55	1.90
Number of goats	2.65	3.50	0.19	1.20	1.94	1.61	1.98	2.09	2.85	3.16	3.87	5.21	4.55
Number of pigs	0.32	1.40	0.03	0.31	1.68	0.18	0.74	0.25	1.06	0.28	1.11	0.60	2.03
Number of chickens	11.82	19.73	0.16	5.93	6.46	7.97	11.14	8.97	8.38	11.28	8.70	25.00	37.64
Number of hoes	5.41	3.50	0.22	3.75	2.18	4.20	2.51	5.23	2.58	5.51	2.31	8.36	5.08
Owens a plough	0.59	0.49	0.22	0.25	0.43	0.49	0.50	0.51	0.50	0.75	0.44	0.95	0.22
Owens a tractor	0.01	0.11	0.04	0.00	0.00	0.01	0.09	0.02	0.13	0.00	0.00	0.03	0.18
Number of wheelbarrows	0.54	0.60	0.24	0.16	0.37	0.34	0.48	0.45	0.53	0.68	0.53	1.09	0.58
Owens a sprayer	0.31	0.46	0.18	0.08	0.28	0.23	0.42	0.27	0.44	0.35	0.50	0.62	0.49
Owens a planter	0.02	0.14	0.04	0.01	0.09	0.01	0.09	0.01	0.09	0.03	0.18	0.04	0.20
Owens an oxcart	0.38	0.49	0.24	0.06	0.23	0.28	0.45	0.23	0.43	0.48	0.50	0.84	0.37
Owens a hand cart	0.01	0.07	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.09	0.02	0.13
Owens a bicycle	0.38	0.49	0.17	0.11	0.31	0.33	0.47	0.36	0.48	0.39	0.49	0.70	0.46
Owens a car	0.03	0.17	0.08	0.00	0.00	0.00	0.00	0.03	0.18	0.03	0.18	0.08	0.26
Owens a truck	0.01	0.10	0.04	0.00	0.00	0.00	0.00	0.02	0.13	0.01	0.09	0.03	0.16
Owens a bike	0.01	0.09	0.03	0.00	0.00	0.00	0.00	0.03	0.16	0.00	0.00	0.02	0.13
Owens a cellphone	0.78	0.41	0.17	0.50	0.50	0.73	0.45	0.86	0.35	0.88	0.33	0.96	0.20
Owens a radio	0.59	0.49	0.16	0.34	0.48	0.54	0.50	0.58	0.50	0.68	0.47	0.84	0.37
Owens a television	0.29	0.45	0.19	0.08	0.28	0.14	0.35	0.25	0.44	0.36	0.48	0.62	0.49
Floor material type													
Mud	0.30	0.46	-0.27	0.84	0.37	0.40	0.49	0.18	0.38	0.06	0.24	0.01	0.09
Cement	0.69	0.47	0.28	0.13	0.34	0.58	0.50	0.82	0.39	0.92	0.28	0.99	0.09
Tiles	0.02	0.13	-0.03	0.03	0.18	0.02	0.13	0.01	0.09	0.03	0.16	0.00	0.00
Wall material type													
Mud	0.09	0.28	-0.08	0.15	0.36	0.13	0.34	0.09	0.29	0.03	0.16	0.03	0.16
Cement bricks	0.49	0.50	0.30	0.01	0.09	0.23	0.43	0.50	0.50	0.81	0.40	0.93	0.26
Mud bricks	0.42	0.49	-0.26	0.84	0.37	0.63	0.48	0.41	0.49	0.17	0.37	0.05	0.22
Roof material type													
Grass	0.34	0.48	-0.27	0.84	0.37	0.56	0.50	0.18	0.39	0.11	0.31	0.03	0.18
Iron sheets	0.14	0.35	-0.01	0.08	0.28	0.25	0.44	0.16	0.37	0.13	0.33	0.10	0.30
Asbestos	0.51	0.50	0.26	0.07	0.26	0.19	0.40	0.66	0.48	0.77	0.43	0.84	0.37
Observations	601			121		120		120		120		120	

SD = Standard deviation; Quintile 1 = is the poorest (or lowest) wealth category; quintile 5 = highest wealth category; Component score is the overall contribution of the variable to the overall principal components score

addresses some of the shortcomings of the standard concentration. The Erreygers (2009) corrected *CI* can thus be expressed algebraically as follows:

$$E(Y_i) = \frac{4\bar{Y}}{(Y^{max} - Y^{min})} \times CI(Y_i) \tag{3}$$

where Y_i is as mentioned earlier, Y^{min} and Y^{max} are the lower and upper values of the dependent variables (i.e. DTM and

CA), $E(Y_i)$ is the corrected concentration index, and $CI(Y_i)$ is as defined in equation (2). Since the chosen outcome variables in this study are all binary (1/0) and substituting equation (2) into equation (3), some small algebraic manipulations give us the following:

$$E(Y_i) = 8 \times Cov(Y, R) \tag{4}$$

To better appreciate the factors influencing socioeconomic status-related disparities in DTM and CA adoption, the study

Table 2 Summary statistics of analysis variables for selected districts in Zimbabwe

Variables	Description and measurement	Goromonzi Mean	Guruve Mean	Mudzi Mean	Wedza Mean
dtma_improved_maize	Binary variable =1 if farmer adopted drought tolerant maize (DTM) seed varieties; 0 otherwise	0.680	0.647	0.892	0.555
ca_farmer	Binary variable =1 if farmer practices conservation agriculture; 0 otherwise	0.320	0.283	0.333	0.303
househ_age	Age of household head in years	51.309	48.503	52.183	55.454
househ_resp_hhead	Binary variable =1 if respondent was the household head; 0 otherwise	0.514	0.551	0.608	0.630
househ_male	Binary variable =1 if gender of household head is male; 0 otherwise	0.743	0.786	0.775	0.714
househ_married	Binary variable =1 if household head is married; 0 otherwise	0.754	0.759	0.775	0.672
househ_num_workers	Number of farm workers	3.063	3.369	3.269	3.314
educ_secondary	Binary variable =1 if household head reached at least secondary school; 0 otherwise	0.480	0.503	0.458	0.454
emp_farmer	Binary variable =1 if household's main occupation is farming; 0 otherwise	0.794	0.898	0.967	0.832
grow_maize	Binary variable =1 if farmer grows maize as major cash crop; 0 otherwise	0.903	0.947	0.950	0.168
agric_extension	Binary variable =1 if farmer has had contact with agricultural extension workers; 0 otherwise	0.537	0.626	0.600	0.714
dist_market	Distance to the nearest main maize market in kilometers	43.474	125.540	132.343	103.973
Land size	Arable land size holding in hectares	1.419	2.727	2.978	2.464
log_landsize	Logarithm of arable land measured in hectares	0.760	1.193	1.271	1.113
asset_quintile1	Binary variable =1 if farmer is in asset quintile 1 (poorest); 0 otherwise	0.131	0.299	0.217	0.134
asset_quintile2	Binary variable =1 if farmer is in asset quintile 2; 0 otherwise	0.200	0.246	0.142	0.185
asset_quintile3	Binary variable =1 if farmer is in asset quintile 3; 0 otherwise	0.234	0.182	0.125	0.252
asset_quintile4	Binary variable =1 if farmer is in asset quintile 4; 0 otherwise	0.194	0.144	0.283	0.210
asset_quintile5	Binary variable =1 if farmer is in asset quintile 5 (richest); 0 otherwise	0.240	0.128	0.233	0.218
Observations		175	187	120	119

Data Source: Data for this study comes from smallholder farmers in four selected districts in Zimbabwe

employed a decomposition strategy recommended by Wagstaff et al. (2003), who showed that the standard concentration index can be expressed in terms of its underlying characteristics using an ordinary least squares (OLS) model (Wagstaff et al. 2003). Even though chosen outcome variables, Y_i are all binary, our study followed the previous literature and estimated an OLS model which is preferable since it generates a unique decomposition of the observed disparities (O'Donnell et al. 2008). To decompose the concentration index into its determining factors, our study used a method pioneered by Wagstaff et al. (2003), later modified to incorporate suggestions by Erreygers (2009), and is expressed as follows:

$$E(Y_i) = 4 \left[\sum_{k=1}^K \beta_k \bar{X}_k \times CI(Y_i)_k + GC_\epsilon \right] \quad (5)$$

where \bar{X}_k represents the mean of the k^{th} explanatory variable, $CI(Y_i)_k$ is the concentration index of the k^{th} covariate, and GC_ϵ is the residual component that captures all the unobservable features. All the analyses were conducted using Stata version 13 (Stata 2013). The corrected concentration index was calculated using a user-written command, *conindex* (O'Donnell et al. 2008) while the decomposition of the concentration

index was completed using the guidelines provided in O'Donnell et al. (2008) with slight modifications to the codes to account for the Erreygers (2009) correction.

3 Results

3.1 Descriptive statistics

Descriptive statistics for the variables used in this study and stratified by district of residence are in Table 2. The mean DTM adoption rate ranged from 55.5% of surveyed farmers in Wedza to about 89.2% in Mudzi. CA adoption at the survey date ranged from 28.3% of farmers in Guruve to 33.3% in Mudzi. Generally, Mudzi had higher rates of CA and DTM adoption. Figure 1 shows how DTM and CA adoption rates compared in the studied districts as observed at the survey date.

In terms of socioeconomic variables, the mean age of sampled household heads ranged from 48.5 years in Guruve to 55.5 years in Wedza. Mean representation of male household headship ranged from 71.4% in Wedza to 78.6% in Guruve. The majority of farmers were married with percentages ranging from 67.2% in Wedza to 77.5% in Mudzi. Average family

labour endowment was almost uniform across districts, ranging from 3.1 persons per household in Goromonzi to 3.4 persons in Guruve. Close to 50% of farmers in all the sampled districts had attained at least a secondary education. The sample was dominated by full-time farmers with mean proportions of farmers who reported farming as their major economic activity ranging between 79.4% in Goromonzi and 96.7% in Mudzi. In addition, at least 90% of sampled farmers in Goromonzi, Guruve and Mudzi reported maize to be one of their major cash crops grown whilst only 16.8% farmers reported the same in Wedza. Most farmers in Wedza grew maize as a food crop. Contact with agricultural extension varied from 53.7% in Goromonzi to 71.4% in Wedza. The average distance to the nearest main maize market (e.g. a Grain Marketing Board (GMB) depot or major town markets such as Mbare Msika) was lowest for Goromonzi (43.5 km away), with Guruve, Mudzi and Wedza having average distances of 125.5, 132.3 and 104 km, respectively, to a major market. Average arable land sizes owned by the household varied by district with the lowest average of 1.4 ha in Goromonzi to about 3.0 ha in Mudzi. Concerning household wealth, Guruve had the largest representation of farmers (54.5%) in the poorest wealth categories (asset quintiles 1 and 2) and the least representation of farmers (27.2%) in the highest wealth categories (asset quintiles 4 and 5). At the other extreme, Wedza had the largest concentration of farmers in the richest

wealth group with about 68% representation in the top three richest asset quintiles combined (3, 4 and 5) and only 31.9% in the lowest two asset quintiles. Mudzi and Goromonzi had almost similar proportions with 64.1% and 66.8% in the top three asset wealth categories respectively.

3.2 Wealth-related inequalities in DTM and CA adoption

Table 3 provides the concentration indices (and their respective standard errors shown in parentheses) for the binary outcome variables of DTM and CA adoption. The reported estimates are the indices based on the Erreygers (2009) corrected concentration index. The concentration indices in Table 3 all show that wealth-related inequalities in DTM (0.123) and CA (0.125) adoption are all statistically significant at the 5% level and mostly pro-rich. Thus the results reveal that observed inequalities in adoption of both DTM and CA exist and that uses of these technologies are highly concentrated among the more affluent smallholder farming households.

To improve understanding of the factors that explain the observed inequalities in the adoption of DTM and CA, a decomposition analysis was performed, with results in the next sub-section. A decomposition analysis splits the corrected

Fig. 1 Distribution of Drought Tolerant Maize (DTM) and Conservation Agriculture (CA) practice adoption in selected districts in Zimbabwe

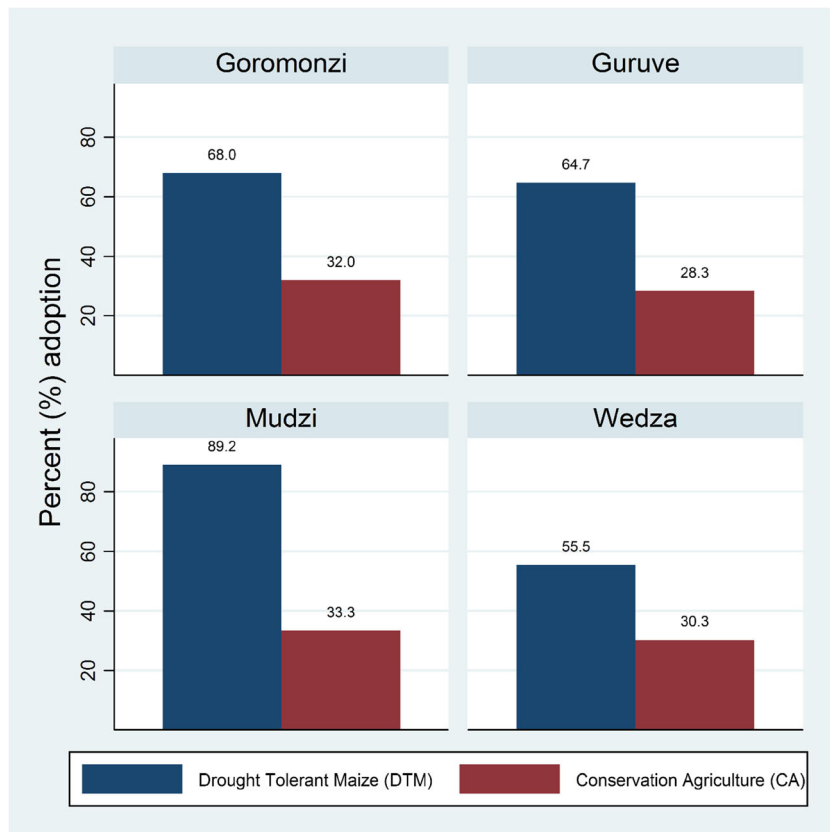


Table 3 Wealth-related inequalities in the use of drought tolerant maize and conservation agriculture as sustainable agriculture practices in Zimbabwe

	Drought tolerant maize		Conservation agriculture	
	Coefficient	Standard error	Coefficient	Standard error
Concentration index	0.123**	(0.044)	0.125**	(0.043)
Number of observations	601		601	

concentration index (inequalities) into its determining factors using the methods described earlier and using equation (5).

3.3 Decomposition of observed inequalities in DTM and CA adoption

Table 4 summarises the decomposition of adoption inequalities of each 'climate-smart' agricultural practice into the percentage contributions of the explanatory variables. A positive (or negative) x% contribution of variable X can be interpreted as follows: wealth-related adoption inequality would, ceteris paribus, be x% lower (or higher) if variable X were equally

distributed across the wealth range (population), or if variable X had a zero-adoption elasticity.

From Table 4, the farmer's age, maize grown as a cash crop, asset wealth (measured by the asset quintile) and district the farmer belongs to, contributed significantly to the observed inequalities in DTM adoption. These parameters explained 13.5%, -23.7%, 63.7% and 22.0%, respectively, of the observed inequalities in DTM adoption. Also, land size, though not significant, explained close to 16.9% of the observed inequalities in adoption of DTM. Asset wealth, therefore, provided the largest contribution to the observed disparities in the adoption of DTM. The positive sign on the asset

Table 4 Contributions of explanatory variables to the overall concentration index for drought tolerant maize and conservation agriculture practices

Variables	Drought tolerant maize				Conservation agriculture			
	Coefficient	Contribution	%	Summed (%)	Coefficient	Contribution	%	Summed (%)
Age of household	0.0044***	0.0166	13.47	13.49	-0.0012	-0.0055	-4.38	-4.38
Head of household	-0.0076	0.0000	-0.03	-0.03	-0.0681	-0.0003	-0.28	-0.28
Male	-0.0827	-0.0094	-7.63	-7.64	0.0787	0.0093	7.45	7.45
Married	0.0857	0.0129	10.48	10.5	-0.086	-0.0135	-10.76	-10.76
Number of workers	0.0014	0.0009	0.72	0.72	0.007	0.0051	4.05	4.05
Education: secondary school	0.0618	0.0090	7.34	7.35	0.0323	0.0045	3.58	3.58
Full-time farmer	0.0025	-0.0002	-0.14	-0.14	0.0345	-0.0026	-2.08	-2.08
Grow maize	0.3860***	-0.0292	-23.68	-23.72	-0.1242*	0.0097	7.75	7.75
Agricultural extension contact	0.0446	0.0094	7.66	7.67	0.1782***	0.0395	31.54	31.54
Distance to the nearest market	0.0003	0.0006	0.52	0.53	0.0975	-0.0025	-1.99	-1.99
Log land size	0.0962	0.0208	16.87	16.90	0.2415***	0.0536	42.83	42.83
Asset quintile 2	0.1744**	-0.0555	-45.07		0.018	-0.0053	-4.23	
Asset quintile 3	0.1253*	0.0002	0.14		-0.0553	-0.0001	-0.06	
Asset quintile 4	0.1474*	0.0473	38.37		-0.0225	-0.0067	-5.34	
Asset quintile 5	0.1349*	0.0864	70.14	63.69	0.02	0.0120	9.62	-0.01
District: Goromonzi	-0.1425**	-0.0142	-11.51		0.1654***	0.0168	13.46	
District: Guruve	-0.1874***	0.0433	35.15		-0.0823	0.0143	11.40	
District: Wedza	-0.0293	-0.0020	-1.65	22.02	-0.102	-0.0068	-5.44	19.42
Residual			-11.33				2.88	
Total			111.33				97.12	
Concentration index		0.1230				0.1251		
Observations		601				601		

***Significant at 1% level; **significant at 5% level; *significant at 10% level. Reported are the marginal probability effects and robust standard errors shown in parentheses. The reference categories are as follows: Household wealth = 1 (poorest); and District = 1 (Mudzi). Coefficient is the linear regression coefficients for the models examining the factors associated with the use of drought tolerant maize and the practice of conservation agriculture in selected districts of Zimbabwe

wealth variable implies that if household wealth were distributed equally across the smallholder farming population, then the observed inequalities in the adoption of DTM would be lower by about 63.7%. The observed contribution of household wealth was large. The positive sign on the age of household also signifies that if the age distribution of farmers was about the same in the sample, observed inequalities would be lower by the respective percentage (i.e., by 13.5%). The negative sign of the variable ‘grow maize’, indicates that if all the farmers grew maize as one of their major cash crops, the observed inequalities would be greater by nearly 23.7%. However, inequalities in DTM adoption would have been lower by 22% if farmers were from the same district (i.e., from Mudzi, the reference category). Furthermore, if land was distributed equally among sampled farmers, observed inequalities would have been less by approximately 16.9%.

For CA, growing maize as the main cash crop, contact with agricultural extension officers, land size holding and district of residence explained 7.5%, 30.3%, 41.9% and 19.5% respectively of the observed inequalities in CA adoption (Table 4). In this case, household wealth was not amongst the notable and significant contributing factors to the observed disparities in CA adoption. Instead, the results show that if all farmers grew maize as the major cash crop, had equal access to extension services, equal land sizes and all came from Mudzi district, the observed inequalities in CA adoption would have been lower by 7.8%, 31.5%, 42.8% and 19.4% respectively. These results point to the overall importance of growing maize as a main cash crop, equal access to extension services, equal distribution of land and equal distribution of other district level parameters (measured in the district dummy variable) in explaining the observed inequalities in the adoption of CA.

For further scrutiny of the observed inequalities in CA and DTM adoption, we analysed how the inequalities compare by district and gender (Table 5).

3.4 Heterogeneities in DTM and CA adoption inequalities

3.4.1 Heterogeneities by geographical location (district)

Results on wealth-related inequalities in CA and DTM adoption by district of residence of the farmer are given in Table 5. The joint significance tests in Table 5 assessed the hypothesis that observed wealth-related disparities in the adoption of DTM and CA are not statistically different across all the districts whilst the alternative hypothesis suggests otherwise. The joint significance test results on DTM adoption showed an insignificant outcome (F-statistic = 1.2198; and P value = 0.3017) indicating that the observed inequalities were not considerably different by farmer’s district of residence. However, the significant concentration index with a magnitude of 0.210 indicated that inequalities in DTM adoption were pro rich, and

significant in Guruve district. In other words, DTM adoption inequalities concentrated in the more affluent population were significant and more pronounced in Guruve district. On the other hand, the joint significance test results (for all districts) on CA adoption revealed significant differences in wealth-related inequalities of CA adoption. These findings pointed to the overall significance of geographical location and associated characteristics in explaining the observed disparities in CA adoption. The significant concentration index (0.327) for Goromonzi district revealed a more pronounced pro-rich distribution of inequalities in CA adoption in that district when compared to the other districts.

3.4.2 Heterogeneities by gender

We also scrutinised the inequalities in CA and DTM adoption by the farmer’s gender. The results shown in Table 6 reveal a significant joint test (F-statistic = 2.9177; p value = 0.0881) by gender on inequalities in DTM adoption but an insignificant joint result for CA adoption (F-statistics = 0.1807; p value = 0.6709). There was a significant and mostly pro-rich disparity in DTM adoption observed by gender. The magnitude of the concentration index for a male farmer (0.169) revealed that inequalities in DTM adoption in the male sample were overwhelmingly pro-rich and significant at the 1% level. Also, the negative concentration index (−0.004) of the female sub-sample, although not significant, revealed that DTM adoption inequalities were pro-poor in the female sub-sample.

The joint test results in Table 6 also showed that the observed pro-rich distribution in CA adoption did not significantly differ by gender of farmer as indicated by the F-statistic and p value reported earlier. However, taking results from the male sub-sample, results showed that inequalities in CA adoption were significant and mostly pro-rich (concentration index = 0.126, significant at the 1% level). Although not statistically different from the male-sub-sample, the inequalities in CA adoption within the female sub-sample were mostly pro-rich (concentration index = 0.083). Overall, the results point to a pro-rich distribution of both DTM and CA adoption which was more pronounced in the sub-sample of male smallholder farmers.

3.4.3 Potential links to food security

To explore the potential links between the adoption of DTM or CA with food security, we plotted local polynomial regressions of CA adoption and DTM adoption separately (see graphs a) to d) of Fig. 2). In Fig. 2a, the dependent variable is a dummy variable for CA adoption and the explanatory variables were each of the livelihood outcomes. The results in Fig. 2a suggest that higher rates of CA adoption are linked to increasing maize yield, including maize set aside for consumption and for sales. In Fig. 2b we plotted local regressions

Table 5 Wealth-related inequalities in adoption of drought tolerant maize and conservation agriculture in selected districts of Zimbabwe

Districts	Counts	Drought tolerant maize (DTMA)		Conservation agriculture (CA)	
		Concentration Index	Standard error	Concentration Index	Standard error
Goromonzi	175	0.140	(0.085)	0.327***	(0.074)
Guruve	187	0.210**	(0.081)	0.037	(0.076)
Mudzi	120	0.062	(0.058)	0.147	(0.102)
Wedza	119	-0.008	(0.106)	-0.062	(0.096)
Joint significance test (all districts): F-statistic		1.2198		3.8287***	
P value		[0.3017]		[0.0098]	
Observations	601			601	

***Significant at 1% level; **significant at 5% level; *significant at 10% level. Presented are the Erreygers (2009) corrected concentration indices with robust standard errors shown in parentheses. The joint significance test for checking statistically significant differences by district assumes equal variables

in which the concentration index (measuring wealth-related inequality in CA adoption at the district level) is the dependent variable. Here, we observed that districts where household wealth was unequally distributed and where CA adoption was highly concentrated in richer or wealthier households, livelihood outcomes were also expected to be better or much higher. A similar pattern was observed for DTM (in Fig. 2c and d). Overall, the results in Fig. 2 suggest that higher levels of DTM and CA adoption are expected to be associated with better livelihood outcomes and hence improved food security.

4 Discussion

Our results showed an overall pro-rich distribution of inequalities in DTM and CA adoption in the smallholder farming areas we studied in Zimbabwe. This outcome can be explained because the more affluent smallholder farmers have an advantage in the uptake of technologies as they can afford the initial investments and capital required to adopt new technologies (Doss 2006; Legese et al. 2009; Mahapatra and Mitchell 2001; Nkala et al. 2011). In Zimbabwe, seed of

improved maize varieties including DTM have a high price in the market, which makes it difficult for the poorer farmers to buy and use them. Similarly with CA, adoption of CA practices is often associated with large additional costs for the smallholder farmer (Rusinamhodzi 2015) including labor costs, costs of equipment (including reduced tillage equipment and sprayers), cost of complementary inputs (e.g., herbicides) which explain the pro-rich distribution of inequalities in the adoption of CA. Additionally, several studies have reported wealth and poverty as important determinants of use of sustainable agriculture practices in smallholder farming (Feder et al. 1985; Makate et al. 2016; Makate et al. 2017; Mazvimavi and Twomlow 2009; Nkala et al. 2011), which is in-line with findings from our study. These results show that poorer smallholder farmers continue to be sidelined in the DTM and CA technology adoption process as it favors richer farmers. This can have negative consequences in efforts directed at reducing poverty and income/wealth inequalities in Zimbabwean rural society and also has negative implications for food security. Adoption of improved technology in agriculture can positively impact food security (see Brüssow et al. 2017; Dibba et al. 2017; Magrini and Vigani 2016), which

Table 6 Heterogeneities in wealth-related inequalities in practice of drought tolerant maize and conservation agriculture by gender of farmer

	Counts	Drought tolerant maize (DTMA)		Conservation agriculture (CA)	
		Concentration Index	Standard error	Concentration Index	Standard error
Male farmers	455	0.169***	(0.050)	0.126*	(0.051)
Female farmers	146	-0.004	(0.094)	0.083	(0.078)
Joint significance test: F- statistic		2.9177*		0.1807	
P value		[0.0881]		[0.6709]	
Observations	601			601	

***Significant at 1% level; **significant at 5% level; *significant at 10% level. Presented are the Erreygers (2009) corrected concentration indices with robust standard errors shown in parentheses. The joint significance test for checking statistically significant differences by gender assumes equal variables

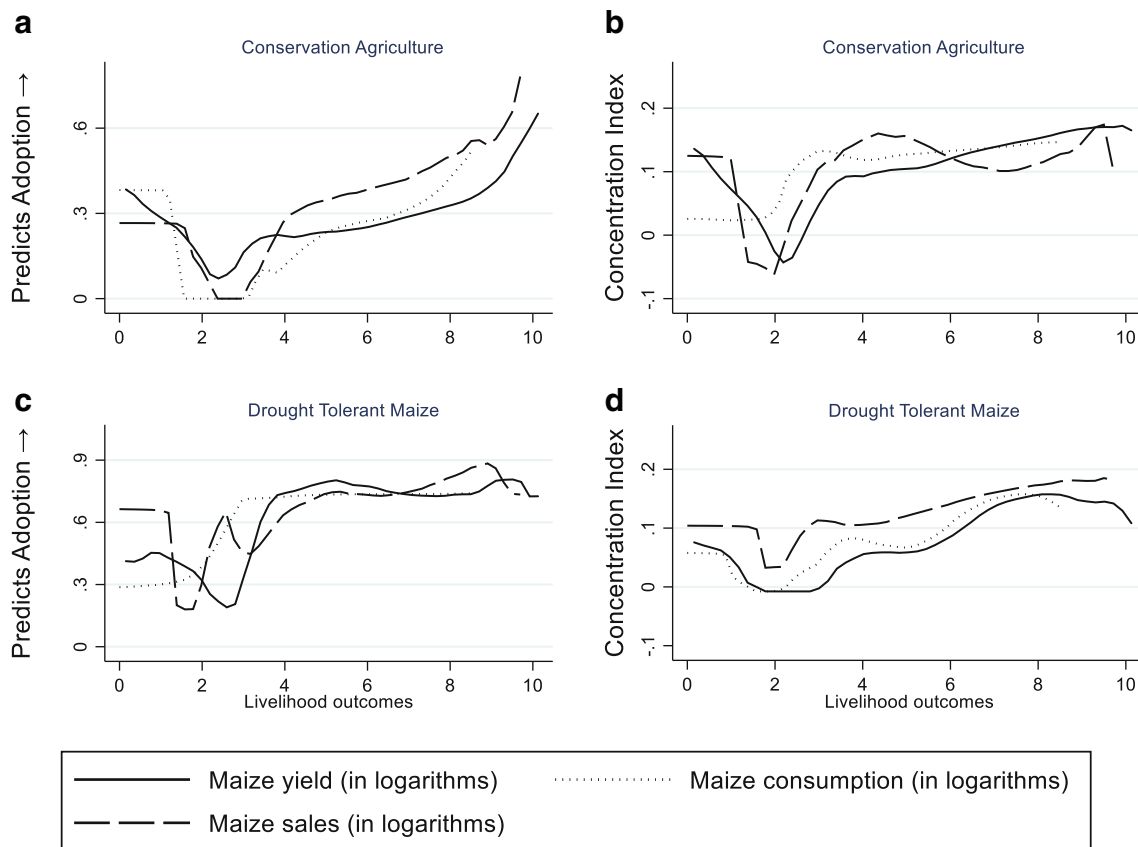


Fig. 2 Higher adoption of ‘climate-smart’ (CSA) technology and an increasing pro-rich distribution in technology adoption, predicts better or more livelihood outcomes for smallholder farmers in Zimbabwe. Local regressions are plotted in the figure. The dependent variables in **a** and **c** are dummy variables for conservation agriculture and drought tolerant maize adoption (see manuscript for more elaborate definitions), respectively. In **b** and **d**, the dependent variables are the concentration index

calculated for each district for conservation agriculture and drought tolerant maize, respectively. All the dependent variables were calculated in such a way that higher values indicate higher adoption (in case of dummy variables for adoption) and positive values for concentration indices indicate a pro-rich distribution in CSA technology adoption. The explanatory variables in each case are the livelihood outcomes, all expressed in logarithms

implies that if CA and DTM continue to be pro-rich, they may not improve the food security and welfare of poor rural societies in Zimbabwe in the longer-term. For climate-resilient maize technologies such as DTM and CA to have greater impacts on maize productivity and on food security in the wider society then they have to be more pro-poor. Deliberate policies and institutional efforts towards subsidized access to DTM seed and complementary CA inputs (including reduced tillage equipment, herbicides and sprayers) by the poor could help. Pro-poor institutional support, technologies and policies generally promote pro-poor agricultural growth in poor areas (Dorward et al. 2004).

A close look at the observed inequalities in DTM adoption by district showed no significant dissimilarities in observed pro-rich inequalities. This result points to an overall pro-rich distribution of inequalities in the use of DTM, which was common in the entire sample of smallholder farmers irrespective of geographical location. Furthermore, stratifying the sample of farmers by gender revealed significant disparities in the adoption rates. A pro-rich distribution of inequalities in

the male sub-sample was evident which points to the fact that relatively rich male farmers enjoyed better adoption rates than their poorer counterparts. This finding is plausible since farming in Zimbabwe is still considered a predominantly male-dominated endeavor by most research and extension staff. In addition, there are indications that advertisement of DTM seed and other improved varieties by seed companies and agro-dealers responsible for seed distribution are biased towards men. Men, as household heads, are generally more likely to have contacts with extension agents, input suppliers and marketers, which gives them an advantage in access to inputs compared to females. For CA, we found an overall pro-rich distribution in adoption, which was significantly different by district of residence. For instance, a more pronounced pro-rich distribution of inequalities in CA adoption was evident in Goromonzi district. Relatively big differences in CA adoption inequalities amongst farmers in that district were evident, which can be explained by a steep wealth gradient among these farmers. Proximity to the capital city of Harare offers better marketing and off-farm employment opportunities for

smallholder farm families in Goromonzi and this could explain the notable pro-rich distribution we found there. However, disparities in observed pro-rich inequalities in CA adoption in all the study areas were not significantly different by gender of farmer. This signifies that affluent male and affluent female farmers both enjoyed greater uptake of CA and subsequent benefits, unlike their poorer counterparts.

We undertook an exercise to decompose the observed inequalities in DTM and CA adoption into their contributing factors. For DTM, wealth was found to be the main contributor of the observed inequalities as it contributed 63.7% of the observed disparities. This result points to wealth as one significant factor that accounts for the discrepancies in DTM adoption. A deepening economic crisis in Zimbabwe has tremendously reduced the purchasing power of most people, particularly those from rural areas. In this regard, access to resources or wealth generally has become an important factor in explaining access to and adoption of improved maize varieties from the formal market. Maize hybrids have been widely marketed to smallholder farmers since 1980 and were instrumental in the second smallholder farmer maize-based green revolution in Zimbabwe during the 1980s and 1990s (Eicher 1995). However, more recently, access to maize hybrids and their use by smallholder farmers has declined due to widespread economic challenges that have reduced the purchasing power of farmers and greatly increased prices of seed on the market. This concurs with literature on DTM adoption, which has found household wealth and access to resources (measured by asset wealth) to be significant factors in adoption (Fisher et al. 2015; Legese et al. 2009; Makate et al. 2017). Our results point to the importance of household wealth in explaining the gradient of DTM adoption. Similarly, in Nepal, Ghimire and Huang (2015) found wealth to be an important covariate explaining adoption and use intensity of improved maize varieties. Wealthier smallholder farmers may have higher propensities to adopt DTM and access to the needed complementary inputs, which can ultimately translate to higher productivity, income and food security. Growing maize as a cash crop, access to land, age of farmer and district were reported as other significant factors that contributed to the observed inequalities in DTM adoption. These findings also concur with previous literature that points to age of farmer (Mugi-Ngenga et al. 2016; Ziervogel and Zermoglio 2009), and land size (Mazvimavi and Twomlow 2009; Neill and Lee 2001) as important factors for the uptake of sustainable agricultural practices. Growing maize as a cash crop was also a significant covariate contributing to the observed inequality, which is unsurprising since the DTM hybrid varieties being promoted recently are expected to yield better, and generate more income and food security for the maize farmer. Accordingly, a decision to grow maize as a cash crop can influence adoption of DTM. Also, different geographical locations can account for other unobserved location-specific

factors which explain DTM adoption decisions (see Makate et al. 2016; Makate et al. 2017). For instance, Makate et al. (2017) found a regional variable to be a significant determinant of DTM adoption in Zimbabwe, with farmers in semi-arid areas such as Mudzi (Natural Region 4) having higher propensities to adopt DTM than their counterparts in wetter areas.

The decomposition analysis for CA points to access to agriculture extension services and land size as the top contributors to the observed inequalities for CA adoption, with 30.3% and 41.9% contributions respectively. This result implies that, *ceteris paribus*, if extension access and land were equitably distributed in the sample of smallholder farmers, observed inequalities would have been lower by those respective proportions. This is plausible since land size and access to extension are considered to be important factors that explain adoption of conservation practices (Feder et al. 1985; Mazvimavi and Twomlow 2009). Furthermore, our results also point to geographical location and growing cash-crop maize as important contributors to the observed inequalities. Geographic location captures several other factors (such as agro potential, market potential, and effectiveness of extension) specific to location that can influence adoption of conservation practices. For instance, Goromonzi and Guruve lie in high rainfall agro-ecological zones whilst Mudzi and Hwedza are in relatively lower rainfall agro-ecological potential zones, which can influence farming decisions. Growing maize as a cash crop can explain the adoption of CA since, in Zimbabwe's smallholder farming systems, maize is one of the most common crops grown under CA (Mazvimavi and Twomlow 2009).

Additionally, we linked DTM and CA adoption and their corresponding wealth-related inequalities (as measured by the corrected concentration index calculated at the district level) to livelihood outcomes (i.e. maize yield, maize consumption, and maize sales). The evidence we found suggests a positive correlation between adoption of these practices and household food security as measured by the livelihood outcomes. In addition, the local polynomial regressions suggested a positive correlation between the pro-rich distribution of inequalities in CA and DTM adoption and livelihood outcomes. This finding implies that if household wealth were equally distributed among the smallholder farmers in our analysis sample, then we would expect livelihood outcomes to be much higher for the overall population. Our results are consistent with much of the previous literature, which has established that both DTM and CA strategies are linked to improved maize productivity in several African environments (Abdoulaye et al. 2018; Jaleta et al. 2018; Lunduka et al. 2017; Mango et al. 2017; Wossen et al. 2017), and that this, in some cases, can translate to improved food security either through direct consumption of the crop output produced or through purchasing other necessities on the market using income from crop sales.

Overall, our results point to the existence of wealth-related inequalities in the adoption of DTM and CA in Zimbabwe,

which may have serious implications for food security. Important climate-resilient maize technologies such as CA and DTM may not significantly improve productivity, incomes and food security of the poor in the long run if they are not used. This is a concern given the continued increase in poverty in rural areas of Zimbabwe where approximately two thirds of the population reside (World Bank 2017). The World Bank (2017) has reported an increase in poverty levels in Zimbabwe from an extremely high 72% in 2011 to about 79% by 2017 (World Bank 2017). Given the predominance of poverty in the Zimbabwean rural populace mainly due to worsening economic challenges and slow development of critical services (e.g. health, water and sanitation, road and market infrastructure), interventions that deliberately serve the poorer segments of society are likely to have greater impact on welfare (poverty reduction). This has been shown by Gomanee et al. (2003) in the case of food aid and Anderson and Feder (2007) for agricultural extension.

Our study had several limitations. We relied on cross-sectional household-level data, which might give an incomplete picture of the dynamics of CA and DTM adoption in Zimbabwe. We also note that even though DTM and CA are important technologies that can improve maize productivity and food security in a changing environment they may also bring uncertainties to the farm. Since they are relatively new technologies, inappropriate implementation of these technologies (particularly CA practices) by farmers may negatively impact on farm yields and food security. In addition, the OLS regression coefficients leading to the decomposition of the observed inequalities into their contributing components represent correlations and do not suggest causality. Despite these concerns, our study provides valuable insights into socioeconomic-status-related inequalities in the adoption of DTM and CA in Zimbabwe.

5 Conclusions and recommendations

In conclusion, this study points to the existence of a pro-rich distribution of inequalities in the adoption of two 'climate-smart' agricultural practices (DTM and CA) in Zimbabwe's smallholder farming population. The results showed a pro-rich distribution of inequalities in DTM adoption evident in all the studied locations but more pronounced within the male-farmer sub-sample. A pro-rich distribution of inequalities in CA adoption was also evident that differed significantly by geographic location, with a more pronounced pro-rich distribution in Goromonzi district, located near to the capital city of Harare. However, inequalities in adoption of CA stratified by gender were not different.

Household asset wealth was identified to be the most important factor contributing to the observed inequalities in the adoption of DTM. Also, the age of the farmer, growing maize

as a cash crop, the district and land size were the other factors significantly contributing to observed inequalities in adoption of DTM. For CA, access to extension services and land size contributed largely to the observed inequalities in adoption. Growing maize as a cash crop and district were the other factors.

Our findings suggest the need for decision makers to consider implementing policies that deliberately focus on the poor and most vulnerable segments of Zimbabwean society to reduce inequalities and ultimately promote the adoption of DTM hybrids by poorer communities. Such policies can work positively in further reducing the gap between the rich and the poor and increase food security of the majority of poor households. For example, subsidizing the price of DTM seed and associated inputs, and ensuring that seed and other complementary inputs are stocked locally to improve access in poorer segments of the farming community in Zimbabwe could be very beneficial. That would improve adoption amongst poorer farmers, which could raise overall livelihood impacts of the technology (including productivity, income, drought resilience, and household food security). Such agricultural subsidy approaches have helped neighboring countries such as Malawi to increase the adoption of improved maize (Denning et al. 2009; Fisher and Kandiwa 2014; Holden and Fisher 2015) and raise food security (Snapp and Fisher 2015). With CA adoption, cheaper policies that improve technical knowledge on the practices and their principles can be highly beneficial. For instance, extension services that are specialized and targeted towards the poorer farmers can improve the livelihood benefits from the practices and uplift poorer farmers. The ultimate outcome from such approaches would be enhanced livelihood benefits from improved maize farming technologies such as CA and DTM to a wider society. Additionally, equitable land distribution policies (well backed by other supportive policies) that target poorer segments of society can also help reduce inequalities in DTM and CA adoption. Local level strategies need to be tailored to specific geographical locations (agro-climatic conditions, agro-potential, market potential and gender) as these may influence adoption of improved maize technologies differently. Broader policies that enhance economic options for farmers through diversification of economic activities or adding value to their farm produce for more income are required if food security is to be permanently improved. Some recent appropriate policy initiatives from government include the financial inclusion drive, value addition and beneficiation drive, and import substitution drive by the Reserve Bank of Zimbabwe.

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Compliance with ethical standards This research met the ethical guidelines of the study country, including adherence to legal requirements.

Conflict of interest The authors confirm that they do not have any conflict of interest.

References

- Abate, T., Magorokosho, C., Tarekegne, A. & Setimela, P. (2015). Maize variety options for Africa: Zimbabwe. *CIMMYT Institutional Multimedia Publications Repository*, <https://repository.cimmyt.org/handle/10883/4659>. Accessed 25 March 2017.
- Abdoulaye, T., Wossen, T., & Awotide, B. (2018). Impacts of improved maize varieties in Nigeria: Ex-post assessment of productivity and welfare outcomes. *Food Security*, *10*(2), 369–379.
- Anderson, J., & Feder, G. (2007). Agricultural extension. In R. Evenson & P. L. Pingali (Eds.), *Handbook of Agricultural Economics* (Vol. 3, pp. 2343–2378).
- Asfaw, A., & Admassie, A. (2004). The role of education on the adoption of chemical fertiliser under different socioeconomic environments in Ethiopia. *Agricultural Economics*, *30*(3), 215–228.
- Baudron, F., Tittone, P., Corbeels, M., Letourmy, P., & Giller, K. E. (2012). Comparative performance of conservation agriculture and current smallholder farming practices in semi-arid Zimbabwe. *Field Crops Research*, *132*, 117–128.
- Bidogeza, J. C., Berentsen, P. B. M., De Graaff, J., & Oude Lansink, A. G. J. M. (2009). A typology of farm households for the Umutara Province in Rwanda. *Food Security*, *1*(3), 321–335.
- Brüssow, K., Faße, A., & Grote, U. (2017). Implications of climate-smart strategy adoption by farm households for food security in Tanzania. *Food Security*, *9*(6), 1203–1218.
- Cairns, J. E., Hellin, J., Sonder, K., Araus, J. L., MacRobert, J. F., Thierfelder, C., & Prasanna, B. M. (2013). Adapting maize production to climate change in sub-Saharan Africa. *Food Security*, *5*(3), 345–360.
- Chikowo, R., Zingore, S., Snapp, S., & Johnston, A. (2014). Farm typologies, soil fertility variability and nutrient management in smallholder farming in sub-Saharan Africa. *Nutrient Cycling in Agroecosystems*, *100*(1), 1–18.
- CIMMYT (2013). The drought tolerant maize for Africa project. DTMA Brief, International Maize and Wheat Improvement Centre.
- CIMMYT (2017). The drought tolerant maize for Africa initiative: General FAQ. <http://dtma.cimmyt.org/index.php/information-tools/software-download/software-faq/95>. Accessed 10-01-2018.
- Davies, M., Guenther, B., Leavy, J., Mitchell, T., & Tanner, T. (2009). Climate change adaptation, disaster risk reduction and social protection: Complementary roles in agriculture and rural growth? *IDS Working Papers*, *2009*(320), 01–37.
- Denning, G., Kabambe, P., Sanchez, P., Malik, A., Flor, R., Harawa, R., Nkhoma, P., Zamba, C., Banda, C., Magombo, C., Keating, M., Wangila, J., & Sachs, J. (2009). Input subsidies to improve smallholder maize productivity in Malawi: Toward an African green revolution. *PLoS Biology*, *7*(1), e1000023.
- DeWalt, B. R. (1975). Inequalities in wealth, adoption of technology, and production in a Mexican Ejido. *American Ethnologist*, *2*, 149–168.
- Dibba, L., Zeller, M., & Diagne, A. (2017). The impact of new Rice for Africa (NERICA) adoption on household food security and health in the Gambia. *Food Security*, *9*(5), 929–944.
- Dorward, A., Fan, S., Kydd, J., Lofgren, H., Morrison, J., Poulton, C., Rao, N., Smith, L., Tehale, H., Thorat, S., Urey, I., & Wobst, P. (2004). Institutions and policies for pro-poor agricultural growth. *Development Policy Review*, *22*(6), 611–622.
- Doss, C. R. (2006). Analyzing technology adoption using microstudies: Limitations, challenges, and opportunities for improvement. *Agricultural Economics*, *34*(3), 207–219.
- Eicher, C. K. (1995). Zimbabwe's maize-based green revolution: Preconditions for replication. *World Development*, *23*(5), 805–818. [https://doi.org/10.1016/0305-750X\(95\)93983-R](https://doi.org/10.1016/0305-750X(95)93983-R).
- Erreygers, G. (2009). Correcting the concentration index. *Journal of Health Economics*, *28*(2), 504–515.
- FAO (2001). The economics of soil productivity in Africa. Soils Bulletin. Rome, Italy: Food and Agriculture Organization.
- Feder, G., Just, R. E., & Zilberman, D. (1985). Adoption of agricultural innovations in developing countries: A survey. *Economic Development and Cultural Change*, *33*(2), 255–298.
- Filmer, D., & Pritchett, L.H. (2001). Estimating wealth effects without expenditure data—or tears: an application to educational enrollments in states of India. *Demography*, *38*.
- Fischer, E., & Qaim, M. (2014). Smallholder farmers and collective action: What determines the intensity of participation? *Journal of Agricultural Economics*, *65*(3), 683–702.
- Fisher, M., & Carr, E. R. (2015). The influence of gendered roles and responsibilities on the adoption of technologies that mitigate drought risk: The case of drought-tolerant maize seed in eastern Uganda. *Global Environmental Change*, *35*, 82–92.
- Fisher, M., & Kandiwa, V. (2014). Can agricultural input subsidies reduce the gender gap in modern maize adoption? Evidence from Malawi. *Food Policy*, *45*, 101–111.
- Fisher, M., Abate, T., Lunduka, R. W., Asnake, W., Alemayehu, Y., & Madulu, R. B. (2015). Drought tolerant maize for farmer adaptation to drought in sub-Saharan Africa: Determinants of adoption in eastern and southern Africa. *Climatic Change*, *133*(2), 283–299.
- Ghimire, R., & Huang, W. C. (2015). Household wealth and adoption of improved maize varieties in Nepal: A double-hurdle approach. *Food Security*, *7*(6), 1321–1335.
- Giller, K., Witter, E., Corbeels, M., & Tittone, P. (2009). Conservation agriculture and smallholder farming in Africa: The heretics' view. *Field Crops Research*, *114*(1), 23–34.
- Giller, K. E., Tittone, P., Rufino, M. C., Van Wijk, M. T., Zingore, S., Mapfumo, P., et al. (2011). Communicating complexity: Integrated assessment of trade-offs concerning soil fertility management within African farming systems to support innovation and development. *Agricultural Systems*, *104*(2), 191–203.
- Gomane, K., Morrissey, O., Mosley, P. & Verschoor, A. (2003). Aid, pro-poor government spending and welfare.
- Gwatkin, D. R., Rutstein, S., Johnson, K., Suliman, E., Wagstaff, A., & Amouzou, A. (2007). Socio-economic differences in health, nutrition, and population within developing countries: An overview. *Nigeria Journal of Clinical Practice*, *10*(4), 272–282.
- Hajizadeh, M., Nandi, A., & Heymann, J. (2014). Social inequality in infant mortality: What explains variation across low and middle income countries? *Social Science and Medicine*, *101*, 36–46.
- Holden, S. T., & Fisher, M. (2015). Subsidies promote use of drought tolerant maize varieties despite variable yield performance under smallholder environments in Malawi. *Food Security*, *7*(6), 1225–1238.
- Holden, S. T., & Quiggin, J. (2016). Climate risk and state-contingent technology adoption: Shocks, drought tolerance and preferences. *European Review of Agricultural Economics*.
- Jaleta, M., Kassie, M., Marenja, P., Yirga, C., & Erenstein, O. (2018). Impact of improved maize adoption on household food security of maize producing smallholder farmers in Ethiopia. *Food Security*, *10*(1), 81–93.
- Kakwani, N., Wagstaff, A., & Van Doorslaer, E. (1997). Socioeconomic inequalities in health: Measurement, computation, and statistical inference. *Journal of Econometrics*, *77*(1), 87–103.
- Kassie, G.T., Erenstein, O., Mwangi, W., Larovere, R., Setimela, P. & Langyintuo, A. (2012). Characterization of maize production in

- southern Africa. Synthesis of CIMMYT/DTMA household level farming system surveys in Angola, Malawi, Mozambique. Nairobi, Kenya: CIMMYT.
- Katengeza, S. P., Holden, S.T. & Lunduka, R.W. (2016). Adoption of drought tolerant maize varieties under rainfall stress in Malawi. 2016 AAAE fifth international conference, September 23–26, 2016, Addis Ababa, Ethiopia: African Association of Agricultural Economists (AAAE).
- Lansing, K., & Markiewicz, A. (2011). Technology diffusion and increasing income inequality. *August [online]*.
- Legese, G., Langyintuo, A.S., Mwangi, W., Jaleta, M. & La Rovere, R. (2009). Household resource endowment and determinants of adoption of drought tolerant maize varieties: A double-hurdle approach. *International Association of Agricultural Economists Conference* (pp. 16–22).
- Lunduka, R., Witman, K., Mateva, I., Magorokosho, C., & Manjeru, P. (2017). Impact of adoption of drought-tolerant maize varieties on total maize production in south eastern Zimbabwe. *Climate and Development*, 1–12.
- Lybbert, T.J., & Carter, M.R. (2015). Bundling drought tolerance and index insurance to reduce rural household vulnerability to drought. In *Sustainable Economic Development* (pp. 401–414): Elsevier.
- Magrini, E., & Vigani, M. (2016). Technology adoption and the multiple dimensions of food security: The case of maize in Tanzania. *Food Security*, 8(4), 707–726.
- Mahapatra, A. K., & Mitchell, C. P. (2001). Classifying tree planters and non planters in a subsistence farming system using a discriminant analytical approach. *Agroforestry Systems*, 52(1), 41–52.
- Makate, M., & Makate, C. (2017). The evolution of socioeconomic status-related inequalities in maternal health care utilization: Evidence from Zimbabwe, 1994–2011. *Global Health Research and Policy*, 2, 1. <https://doi.org/10.1186/s41256-016-0021-8>.
- Makate, C., Wang, R., Makate, M., & Mango, N. (2016). Crop diversification and livelihoods of smallholder farmers in Zimbabwe: Adaptive management for environmental change. *SpringerPlus*, 5(1), 1–18.
- Makate, C., Wang, R., Makate, M., & Mango, N. (2017). Impact of drought tolerant maize adoption on maize productivity, sales and consumption in rural Zimbabwe. *Agrekon*, 56(1), 67–81.
- Makate, C., Makate, M., & Mango, N. (2018). Farm types and adoption of proven innovative practices in smallholder bean farming in Angonia district of Mozambique. *International Journal of Social Economics*, 45(1), 140–157.
- Mango, N., Zamasiya, B., Makate, C., Nyikahadzo, K., & Siziba, S. (2014). Factors influencing household food security among smallholder farmers in the Mudzi district of Zimbabwe. *Development Southern Africa*, 31(4), 625–640.
- Mango, N., Siziba, S., & Makate, C. (2017). The impact of adoption of conservation agriculture on smallholder farmers' food security in semi-arid zones of southern Africa. *Agriculture and Food Security*, 6(1), 32.
- Masih, I., Maskey, S., Mussá, F. E. F., & Trambauer, P. (2014). A review of droughts on the African continent: A geospatial and long-term perspective. *Hydrology and Earth System Sciences*, 18(9), 3635–3649.
- Mazvimavi, K., & Twomlow, S. (2009). Socioeconomic and institutional factors influencing adoption of conservation farming by vulnerable households in Zimbabwe. *Agricultural Systems*, 101(1), 20–29.
- Milán, M. J., Bartolomé, J., Quintanilla, R., García-Cachán, M. D., Espejo, M., Herráiz, P. L., Sánchez-Recio, J. M., & Piedrafitá, J. (2006). Structural characterisation and typology of beef cattle farms of Spanish wooded rangelands (dehesas). *Livestock Science*, 99(2), 197–209.
- Mugi-Ngenga, E. W., Mucheru-Muna, M. W., Mugwe, J. N., Ngetich, F. K., Mairura, F. S., & Mugendi, D. N. (2016). Household's socio-economic factors influencing the level of adaptation to climate variability in the dry zones of eastern Kenya. *Journal of Rural Studies*, 43, 49–60.
- Murray, U., Gebremedhin, Z., Brychkova, G. & Spillane, C. (2016). Smallholder farmers and climate smart agriculture technology and labor-productivity constraints amongst women smallholders in Malawi. Gender, Technology and Development, <https://doi.org/10.1177/0971852416640639>.
- Neill, S. P., & Lee, D. R. (2001). Explaining the adoption and disadoption of sustainable agriculture: The case of crop crops in northern Honduras. *Economic Development and Cultural Change*, 49(4), 793–820.
- Nkala, P., Mango, N., & Zikhali, P. (2011). Conservation agriculture and livelihoods of smallholder farmers in Central Mozambique. *Journal of Sustainable Agriculture*, 35(7), 757–779.
- Nyikahadzo, K., Siziba, S., Mango, N., Mapfumo, P., Adekunle, A., & Oluwole, F. (2012). Creating food self reliance among the smallholder farmers of eastern Zimbabwe: Exploring the role of integrated agricultural research for development. *Food Security*, 4(4), 647–656.
- O'Donnell, O., van Doorslaer, E., Wagstaff, A., & Lindelow, M. (2008). *Analyzing health equity using household survey data a guide to techniques and their implementation*. Washington DC: World Bank.
- Pangapanga, P. I., Jumbe, C. B., Kanyanda, S., & Thangalimodzi, L. (2012). Unravelling strategic choices towards droughts and floods' adaptation in southern Malawi. *International Journal of Disaster Risk Reduction*, 2, 57–66.
- Ranum, P., Peña-Rosas, J. P., & Garcia-Casal, M. N. (2014). Global maize production, utilization, and consumption. *Annals of the New York Academy of Sciences*, 1312(1), 105–112.
- Rusinamhodzi, L. (2015). Tinkering on the periphery: Labour burden not crop productivity increased under no-till planting basins on smallholder farms in Murehwa district, Zimbabwe. *Field Crops Research*, 170, 66–75.
- Siziba, S. (2008). Assessing the adoption of conservation agriculture in Zimbabwe's smallholder sector. University of Hohenheim, Germany.
- Snapp, S. S., & Fisher, M. (2015). "Filling the maize basket" supports crop diversity and quality of household diet in Malawi. *Food Security*, 7(1), 83–96.
- Solano, C., León, H., Pérez, E., & Herrero, M. (2001). Characterising objective profiles of Costa Rican dairy farmers. *Agricultural Systems*, 67(3), 153–179.
- Somda, J., Kamuanga, M., & Tollens, E. (2005). Characteristics and economic viability of milk production in the smallholder farming systems in the Gambia. *Agricultural Systems*, 85(1), 42–58.
- Stata, S. C. (2013). *Release 13. Statistical Software*. College Station, Texas: StataCorp LP.
- Thierfelder, C., & Wall, P. C. (2010). Investigating conservation agriculture (CA) systems in Zambia and Zimbabwe to mitigate future effects of climate change. *Journal of Crop Improvement*, 24(2), 113–121.
- Thierfelder, C., Cheesman, S., & Rusinamhodzi, L. (2012). A comparative analysis of conservation agriculture systems: Benefits and challenges of rotations and intercropping in Zimbabwe. *Field Crops Research*, 137, 237–250.
- Thierfelder, C., Chivenge, P., Mupangwa, W., Rosenstock, T. S., Lamanna, C., & Eyre, J. X. (2017). How climate-smart is conservation agriculture (CA)? – Its potential to deliver on adaptation, mitigation and productivity on smallholder farms in southern Africa. *Food Security*, 9(3), 537–560.
- Tittonell, P., Muriuki, A., Shepherd, K. D., Mugendi, D., Kaizzi, K. C., Okeyo, J., Verchot, L., Coe, R., & Vanlauwe, B. (2010). The diversity of rural livelihoods and their influence on soil fertility in agricultural systems of East Africa—a typology of smallholder farms. *Agricultural Systems*, 103(2), 83–97.

- van Doorslaer, E., Wagstaff, A., Bleichrodt, H., Calonge, S., Gerdtham, U. G., Gerfin, M., Geurts, J., Gross, L., Häkkinen, U., Leu, R. E., O'Donnell, O., Propper, C., Puffer, F., Rodríguez, M., Sundberg, G., & Winkelhake, O. (1997). Income-related inequalities in health: Some international comparisons. *Journal of Health Economics*, *16*(1), 93–112.
- Wagstaff, A. (2005). The bounds of the concentration index when the variable of interest is binary, with an application to immunization inequality. *Health Economics*, *14*(4), 429–432.
- Wagstaff, A., Paci, P., & van Doorslaer, E. (1991). On the measurement of inequalities in health. *Social Science and Medicine*, *33*(5), 545–557.
- Wagstaff, A., van Doorslaer, E., & Watanabe, N. (2003). On decomposing the causes of health sector inequalities with an application to malnutrition inequalities in Vietnam. *Journal of Econometrics*, *112*, 207–223.
- Wossen, T., Abdoulaye, T., Alene, A., Feleke, S., Menkir, A., & Manyong, V. (2017). Measuring the impacts of adaptation strategies to drought stress: The case of drought tolerant maize varieties. *Journal of Environmental Management*, *203*, 106–113.
- World Bank (2017). Zimbabwe economic update: the state in the economy. (pp. 1–59). Harare Zimbabwe: The World Bank.
- Ziervogel, G., & Zermoglio, F. (2009). Climate change scenarios and the development of adaptation strategies in Africa: Challenges and opportunities. *Climate Research*, *40*(2–3), 133–146.
- Zimbabwe National Statistics Agency (2017). Zimbabwe: Administrative Division. Accessed 15/01/2018.



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