Food Policy 125 (2024) 102629

Contents lists available at ScienceDirect

Food Policy

journal homepage: www.elsevier.com/locate/foodpol

Food security and poverty reduction effects of agricultural technologies adoption – a multinomial endogenous switching regression application in rural Zimbabwe

Akuffo Amankwah [a,*], Tendai Gwatidzo [b]

[a] Living Standards Measurement Study, Development Data Group, World Bank, 1818 H St, NW, Washington DC, 20433, USA
[b] School of Economics and Finance, University of the Witwatersrand, Johannesburg South Africa

ARTICLE INFO

JEL Codes:
C34
O12
O33
Q12
Q16
Q18

Keywords:
Joint technology adoption
Multiple agricultural technologies
Welfare effects
Multinomial endogenous switching/treatment regression
Rural Zimbabwe

ABSTRACT

Using nationally representative household survey data and the multinomial endogenous switching regression (MESR) procedure, this study examines the productivity, food security, and poverty reduction effects of adopting improved seed and inorganic fertilizer in rural Zimbabwe. The results show that the joint adoption of improved seed and inorganic fertilizer is facilitated by household ownership of farm mechanization, years of education of the household heads, presence of a wage worker in the household, access to irrigation facilities, and government extension services. The MESR results show that the adoption of improved seed and inorganic fertilizer, as well as their joint usage, have productivity and welfare-enhancing effects on farming households in rural Zimbabwe. More importantly, we find that while the technologies appear to impact food consumption negatively, households using the technologies jointly in production are more food secure and eat more diverse foods. This implies government efforts to promote the joint adoption of the two technologies in rural Zimbabwe are encouraged.

1. Introduction

Agriculture continues to be at the forefront of the development agenda in most countries in Sub-Saharan Africa (SSA) as it serves as the main source of livelihood for a substantial share of the population, especially those in rural areas (World Bank, 2008). In most countries in SSA, poverty reduction strategies of governments and development partners focus on the agricultural sector (Suri and Udry, 2022; Collier and Dercon, 2014). Food and nutrition security is also dependent on the agricultural sector (Dillon et al., 2015; Giller, 2020; Slavchevska, 2015). Thus, improving the performance of the sector through increased productivity and market orientation is vital in helping SSA achieve relevant sustainable development goals (SDGs), including food and nutrition security, income generation, and poverty reduction. Growth in agriculture productivity in SSA has historically been driven by increasing area under cultivation, with limited use of improved and sustainable practices (IFAD, 2011; OECD/FAO, 2016). Replicating Asia's green revolution in Africa requires the development and extensive use of high-yielding seed varieties and fertilizers. The adoption of improved agricultural technologies is vital for increasing agricultural productivity and boosting food and nutrition security, as well as poverty reduction in SSA (Kassie et al., 2018; Diao et al., 2010).

The impact of agricultural technologies and sustainable practices on rural households' welfare is well established in the empirical literature, including those on Africa (Wongnaa et al., 2018; Kassie et al., 2011; Gitonga et al., 2010; Amankwah et al., 2018; Amankwah and Quagrainie, 2019; Morris et al., 1999), and those focusing on other regions (Bellon and Risopoulos, 2001; Bellon et al., 2006; Wu et al., 2010; Becerril and Adbulai, 2010; Mendola, 2007). Most of these studies have mostly examined the welfare effect of a single technology, with only a few looking at the impact of joint use of multiple technologies (Tekle-wold et al., 2013; Khonje et al., 2018; Tesfaye et al., 2020). In the presence of multiple technologies, farming households generally tend to use different combinations, instead of a single technology during the production process. The use of technological packages has been found to improve welfare substantially (in terms of magnitude), compared to

* Corresponding author.
E-mail addresses: aamankwah@worldbank.org (A. Amankwah), Tendai.Gwatidzo@wits.ac.za (T. Gwatidzo).

https://doi.org/10.1016/j.foodpol.2024.102629
Received 11 September 2023; Received in revised form 28 March 2024; Accepted 8 April 2024
Available online 16 April 2024
0306-9192/© 2024 The World Bank. Published by Elsevier Ltd. This is an open access article under the CC BY IGO license (http://creativecommons.org/licenses/by/3.0/igo/).

employing a single technology in production (Teklewold et al., 2013; Khonje et al., 2018; Tesfaye et al., 2020).

Specifically in Zimbabwe, Pindiriri (2018) examines the drivers and impact of modern technology (at least hybrid or improved seed variety, a tractor, a pump, a harvester, a planter, a generator, modern irrigation equipment or modern weather forecasting equipment) in Hurungwe district using household income as a measure of welfare, without considering the multidimensionality of welfare. While there are a number of studies examining the impact of technology adoption on welfare in SSA and a few on Zimbabwe, there is no such study that uses nationally representative and rich household survey data in rural Zimbabwe, especially in the context of multidimensional welfare measures.

This study examines the welfare effects of improved seed and inorganic fertilizer, and their joint adoption in rural Zimbabwe. Though these technologies have been in existence for quite some time, the welfare effects of their joint usage are yet to be examined in the Zimbabwean context. Thus, the study seeks to fill this knowledge gap by using a unique nationally representative household survey data from rural Zimbabwe to examine the impact of improved seed and inorganic fertilizer joint adoption on household welfare, focusing on consumption expenditure, poverty headcount, food share in total household consumption expenditure, food security, composite welfare, and maize productivity. The use of several welfare measures, including composite welfare, amplifies the utility of this study. This will help in understanding the multidimensional benefits that households derive from jointly using these technologies. The study also estimates the welfare effects of using the technologies individually versus jointly in production, thereby allowing for measuring the additional welfare gains from their joint usage.

Farming households in rural Zimbabwe are interesting to study for a number of reasons. First, the agriculture sector, that serves as the main source of livelihood for majority of the rural dwellers in Zimbabwe is at the centre of the country's economy (World Bank, 2019; Government of Zimbabwe, 2018). Indeed, if the sector sneezes, the entire economy catches a cold. Second, given its central role in the economy, the government has introduced a number of programs to boost the sector's performance, including the Command Agriculture Program that sought to, among other things, increase the use of improved seed and inorganic fertilizer. Third, to address historical imbalances and decongest the communal areas, where majority of Zimbabwean natives reside, the government has, since the 1980s, been implementing land reforms. These reforms have impacted the sector in different ways, including productivity and input use of smallholder farmers in these areas.

This paper uses the multinomial endogenous switching regression (MESR) and multinomial endogenous treatment effects (METE) methodologies to control for endogeneity resulting from both observed and unobserved variables. As a robustness check, the propensity score matching (PSM) and instrumental variables (IV) procedures are also employed. The data used in this study is nationally representative, and contains household- and plot-level characteristics, making it unique for this study.

The results show in general that the technologies have productivity and welfare-enhancing effects on households in rural Zimbabwe. More importantly, the results show that the welfare gains from the use of improved seed and inorganic fertilizer as a package are significantly higher than if the technologies were used independently in production. For instance, the maize-productivity effect of using both technologies is about 48 percentage points higher than if only improved seed were used in production (65 % vs. 17 %). In addition, while the technologies appear to impact food consumption expenditure negatively, households using these technologies are more food secure and eat more diverse foods; the number of food groups consumed increases by 23 % for joint use of the technologies and 9 % and 12 % for sole adoption of improved seed and inorganic fertilizer, respectively. The joint use of the technologies also reduces the share of households that are poor and food insecure, while at the same time, positively impacting food security.

The rest of the paper is structured as follows. Section 2 provides Zimbabwe country context. In Section 3, we present the conceptual framework and econometric strategy used in the study, while Section 4 contains information on data and descriptive results. Section 5 contains the econometric results, while conclusions of the study are presented in Section 6.

2. Country context

Zimbabwe is one of the poorest countries in SSA. According to the Zimbabwe National Statistics Agency (ZimStat, 2017), the poverty headcount stood at 70.5 % in 2017, with rural and urban shares being 86 % and 37 %, respectively. In the same year, the national extreme poverty rate, defined as a shortfall below the lower poverty line (food line), was 29.7 %; rural and urban rates were 40.9 % and 4.4 %, respectively. This means that poverty in Zimbabwe, like other countries in SSA, is predominantly a rural phenomenon. That notwithstanding, the food and nutritional security situation in the country appear to have improved in recent years. The share of the population that were severely food insecure dropped from 35.5 % in 2014/16 to 31.3 % in 2019/21 (FAO, IFAD, UNICEF, WFP and WHO, 2021). Similarly, the prevalence of stunting in children under 5 years of age declined from 31.4 % in 2012 to 23 % in 2020. Conversely, moderate or severe food insecurity increased from 64.7 % to 73 % between 2014/16 and 2019/21.

The agriculture sector in Zimbabwe is a major hub for employment, foreign exchange earnings and food production (ensuring food security), and supplies inputs for use in the manufacturing and other economic sectors of the country. Specifically, the agriculture sector contributes about 10 % to GDP, employs about two thirds of the country's labor force (World Bank, 2019), supplies 60 % of raw materials required by the manufacturing sector, and contributes 40 % of the country's total export earnings.[1] The performance of Zimbabwe's agricultural sector is therefore directly linked to the economic performance and food security situation of the country.

The performance of Zimbabwe's agricultural sector has, however, been marred by a myriad of challenges, resulting in low productivity. Over the past two decades, maize (the main staple food) yield has averaged around 0.75 metric tons per hectare (USDA, 2021), which is low compared to other countries in the region. Climate-related shocks are now more frequent and intense. For example, over the period 2000 – 2020, the country experienced seven droughts, an average of one drought every 3 years (World Bank, 2019). The low productivity in the agricultural sector meant that, even with the large share of arable land and inorganic fertilizer application per hectare (30Kg/ha compared to 14Kg/ha in the SSA),[2] the country could not meet its national food requirements, especially for wheat and maize. As a result, the government resorted to maize and wheat importation, putting further pressure on the country's limited foreign exchange reserves.

Given the critical role played by the agricultural sector in Zimbabwe, the government has, over the years, implemented a number of programs to stimulate productivity. These include land reforms (to address historical imbalances in land access) and other interventions (e.g., allocating inputs and funds to farmers). Zimbabwe's land reform program was implemented in two phases. The first phase started in the early 1980 s when the country gained independence (1980–1999). Phase two, also called the Fast Track Land Reform Program (FTLRP), started in the early 2000 s. Though the immediate objective of the reform was

[1] See the World Bank's World Development Indicators website for more information: https://databank.worldbank.org/source/world-development-indicators.

[2] See the World Bank's World Development Indicators website for more information: https://databank.worldbank.org/source/world-development-indicators.

ensuring equitable access to land through redistribution, the long-term goal was to boost productivity of smallholder farmers (Zikhali, 2008; Mazwi et al., 2018). The productivity goal of the reform was however not achieved, but rather, agricultural productivity plummeted between 2000–2008, leading to severe food insecurity and increased importation of staples.

To reverse the downward spiral of the agricultural sector's performance, the government has implemented other interventions in recent years, including the Command Agriculture Program (CAP). The CAP is a state-led contract farming scheme aimed at increasing agricultural productivity through the provision of farm inputs (such as fertilizer and seeds), in the form of loans, and focused especially on maize and wheat sub-sectors.

3. Conceptual framework and econometric strategy

In a randomized controlled experiment where households/subjects are randomly assigned to treatments, the effect of a given intervention is simply estimated by comparing the outcome variable of the intervention sample to the non-intervention sample (Rosenbaum. 1984; Gertler et al., 2011; Guo and Fraser, 2010; and Rubin and Imbens, 2015). In a non-randomized observational study where households are not randomly assigned to specific treatments, they could self-select themselves into any treatment category based on their observed and unobserved characteristics, leading to selection bias. In the presence of selection bias, the use of ordinary least squares (OLS) estimator could lead to bias and inconsistent estimates, and misleading policy implications. Given the study's underlying technologies (improved seed, inorganic fertilizer, and both), it is important to employ an approach that considers these combinations and the potential multiple sources of endogeneity, both observed and unobserved. In situations where self-selection is due to observed household characteristics, the PSM technique has been used (Kassie et al., 2013; Becerell and Abdulai, 2010; Amankwah et al., 2018). However, the PSM technique cannot correct for bias resulting from unobserved factors (Jaleta et al., 2016).

This study employs the MESR and the METE models to correct for selection bias resulting from observed and unobserved factors, allowing for obtaining consistent estimates. MESR and the METE each follow two simultaneous stages.[3] In the first stage, the drivers of a household's decision to adopt the underlying technologies are estimated using the multinomial selection logit regression model (MNLR), while taking into account the interrelationships between the technologies. Following the first stage, inverse mills ratios (IMR) are estimated from the predicted probabilities of the MNLR. In the second stage, the effects of each technology on the productivity and welfare outcome variables are evaluated using OLS, with the IMR from the first stage included as additional covariate to correct for selection bias.

3.1. Multinomial selection logit model

A household's decision to use improved seed, inorganic fertilizer, and their combination follows a random utility theory where they compare the utility from using these technologies (Kassie et al., 2011; 2018 Gitonga et al., 2013; Amankwah et al., 2018; Becerril and Abdulai, 2010). Let U_{ij} be the utility that the i^{th} household derives from using technology j $(j = 1, 2, 3, 4)$ and U_{ik} be the utility otherwise. The household adopts a given technology if $(U_{ij} > U_{ik}), \forall j \neq k$. The expected utility, conditional on observed household, plot and geographic variables, and unobserved characteristics, is given by the index function:

$$U_{ij}^{*} = X_i\gamma_j + \varepsilon_{ij} \tag{1}$$

where X_i represents a set of observed exogenous variables (including household, plot and geographic factors), γ_j is a vector of parameters to be estimated, and ε_{ij} is the unobserved error term. Let T be an index function that denotes a household's choice of the underlying technology, such that:

$$T_i = \begin{cases} 1 & iff \quad U_{i1}^{*} > \underset{k \neq 1}{max}(U_{ik}^{*}) \quad or \quad \eta_{i1} < 0 \\ & \cdots \\ & \cdots \\ J & iff \quad U_{iJ}^{*} > \underset{j \neq k}{max}(U_{ik}^{*}) \quad or \quad \eta_{iJ} < 0 \end{cases} \tag{2}$$

here $\eta_{ij} = max(U_{ik}^{*} - U_{ij}^{*}) < 0$ (Bourguignon et al., 2007). The implication of equation (2) is that the i^{th} household will adopt technology j if it provides greater expected utility than any other alternative, that is, if $\eta_{ij} = \underset{j \neq k}{max}\left(U_{ij}^{*} - U_{ik}^{*}\right) > 0, \ \forall j \neq k$. Assuming that ε_{ij} are independently Gumbel distributed, the probability that a household will use technology j can be expressed as a multinomial logit model following McFadden (1973) as:

$$p_{ij} = \Pr(\eta_{ij} < 0|X_i) = \frac{\exp(X_i\gamma_j)}{\sum_{k=1}^{J}\exp(X_i\gamma_j)} \tag{3}$$

which is estimated using the maximum likelihood procedure (*mlogit* command in Stata 18).

3.2. Second stage – Outcome equation

In the second stage of the MESR, the relationship between each outcome variable and a set of exogenous variables Z_i, is estimated for each technology regime (1 = no adoption, 2 = improved seed only, 3 = inorganic fertilizer only, and 4 = both improved seed and inorganic fertilizer). The outcome equation for each technology regime (j) is:

$$\begin{cases} Regime 1: Y_{i1} = Z_i\beta_1 + e_{i1} \quad if \quad T = 1 \\ \quad \cdots \\ \quad \cdots \\ Regime J: Y_{iJ} = Z_i\beta_J + e_{iJ} \quad if \quad T = J \end{cases} \tag{4}$$

where the $Y_{ij}^{'}s$ are the outcome variables of the i^{th} household in regime j and $e_{ij}^{'}s$ are distributed as $E\left(e_{ij}|X, Z\right) = 0$ and $var\left(e_{ij}|X, Z\right) = \sigma_j^2$. Note that $Y_{ij}^{'}s$ are observed if and only if one technology package is applied by the household. Given that the error terms of the adoption equations, ε_{ij}, are not independent due to the presence of unobserved factors, the use of OLS will lead to bias and inconsistent estimates. In order to obtain consistent estimates of β_j, a selection correction term of the alternative choice is needed in the above equation. Following Di Falco (2014), Kassie et al. (2015), Teklewold et al. (2013), the second stage of the MESR is estimated as follows, including the correction terms:

$$\begin{cases} Regime 1: Y_{i1} = Z_i\beta_1 + \sigma_1\lambda_1 + e_{i1} \quad if \quad T = 1 \\ \quad \cdots \\ \quad \cdots \\ Regime J: Y_{iJ} = Z_i\beta_J + \sigma_J\lambda_J + e_{iJ} \quad if \quad T = J \end{cases} \tag{5}$$

where σ_j is the covariance between e_{ij} and ε_{ij}, and λ_j is the estimated IMR computed using the predicted probabilities from the multinomial logit model in Equation (3). The IMR is given as:

$$\lambda_j = \sum_{k \neq j}^{J} \rho_j \left(\frac{P_{ik}\ln(P_{ik})}{1 - P_{ik}} + \ln\left(P_{ij}\right)\right) \tag{6}$$

where ρ is the correlation between e_{ij} and ε_{ij}. Note that in the

[3] Both the MESR and METE follow the same approach. The MESR is for continuous outcome variables, while the METE is for binary outcome variables. In what follows, we focus on the derivation of the MESR which could be extended to the METE. See Khonje et al. (2018) and Deb and Trivedi (2006) for details on the METE.

multinomial model, there are J − 1 selection correction terms, up to the number of alternative technologies. The standard errors in Eq. (5) are bootstrapped to account for the heteroskedasticity arising from the generated regressor (λ_j) in the second stage.

In order to control for unobserved heterogeneity in estimating the welfare effects of the technologies, we use access to government extension services, and distance to input markets as instruments. Other related empirical studies (e.g., Khonje et al., 2018, Abdulai, 2016; Kassie et al., 2015) have employed these variables as instruments. Agricultural extension agents disseminate information about new technologies in terms of benefits, costs, access, and best application procedures. Market access, captured by distance is also vital and critical driver of access to improve agricultural practices, especially in SSA. The chosen instrument should generally satisfy two conditions – correlated with the endogenous variable(s), but uncorrelated with the outcome variable(s). The joint test result of these variables in the MNLR shows that they are jointly significant, and thus vital for households' decision to adopt the technologies. We also conducted simple falsification tests to establish that they do not affect the outcome variables (Table A1). The falsification tests show in general that these variables do not explain household welfare in the study area. Thus, we do not expect these variables to directly impact agricultural productivity and household welfare except through their effect on the technologies' adoption decisions. It is important to note that these instruments are not perfect irrespective of the test results and the intuitive justification provided. That notwithstanding, instruments are as good as the available data can provide after subjecting them to the necessary exclusion restriction tests (Atta-Ankomah and Osei, 2021).

3.3. Estimation of average treatment effects

We estimate the average treatment effects of each alternative technology by comparing the expected value of each outcome of adopters and non-adopters (counterfactual case) using the estimated IMR (λ_j) as follows. For adopters with actual adoption, the expected value of the outcome variable is:

$$E\left(Y_{ij}|T=j\right) = Z_i\beta_j + \sigma_j\lambda_j \quad if \quad T=j \quad (j=2,3,4) \tag{7a}$$

And for adopters had they not adopted (counterfactual)

$$E(Y_{i1}|T=j) = Z_i\beta_1 + \sigma_1\lambda_j \quad ifT=j \quad (j=2,3,4) \tag{7b}$$

Such that the average treatment effect (ATT) of each alternative technology is the difference between the actual and counterfactual as:

$$ATT = E\left(Y_{ij}|T=j\right) - E(Y_{i1}|T=j) = Z_i\left(\beta_j-\beta_1\right) + \lambda_j\left(\sigma_j-\sigma_1\right) \tag{8}$$

where first term is the difference in mean outcome of adopters and non-adopters have they had the same observed characteristics, while the second term is the selection correction that indicate the change in outcome resulting from differences in unobserved factors. These were estimated using the *selmlog* (for continuous outcome variables) and *mtreatreg* (for binary outcome variables) procedures in Stata 18.

4. Data and descriptive statistics

4.1. Data

The data used for the analysis comes from the Agricultural Productivity Module (APM) survey conducted by ZimStat in 2017, with financial and technical assistance from the World Bank. The APM was modeled to follow the Living Standards Measurement Study Integrated Survey on Agriculture (LSMS-ISA) Initiative of the World Bank. The APM consisted of two visits – post planting and post-harvest – with different information collected in each visit to the household. The first visit took place after planting during March-May 2017, while the second visit was conducted between September to November 2017; the fieldwork was scheduled to coincide with the 2016/17 agricultural season. The APM survey focused only on rural areas where agriculture is the predominant source of livelihood.

The APM sample is a subsample of the Poverty, Income, Consumption and Expenditure Survey (PICES) 2017 sample drawn from the 2012 population and housing census (see ZimStat, 2019, for details on the sample design). Household level information, including welfare variables, of the APM sample were obtained from the PICES 2017 datasets. The APM sample was designed to be nationally representative as well as representativeness at four domains – Communal Lands, Small Scale Commercial Farms, A1 Farms, and Old Resettlement Areas strata – using a two-stage cluster sampling procedure. In the first stage, enumeration areas (EAs) were selected from the PICES 2017 EAs that were canvased in March, April and May 2017 using probability proportional to size (PPS) procedure, while the second stage involved the selection of households from these EAs using systematic random sampling approach. A total of 2,552 households were selected in the second stage, of which 2,338 were successfully interviewed. Following additional cleaning and restricting the sample to only households that produced maize, the final analytical sample was 1,976 households and 4,738 plots. Households operated about 2.4 plots on average during the season. All analysis in this paper is done at the household level unless otherwise stated.

4.2. Definition of salient variables and descriptive results

In Table 1, the descriptive statistics of the technologies, outcome and conditioning variables used in the analysis are presented (see Table A6 for plot-level summary statistics). Given that some of the households in the sample operated multiple plots and the analysis in this paper is conducted mainly at the household level, it is important to provide context to the technology adoption variables used in the study. A household is considered to have adopted a given technology if they applied the respective technology on at least one of their cultivated plots during the 2016/17 agricultural season.

The data shows that 82 % of the households used improved seed, while 66 % adopted inorganic fertilizer. However, 25 % and 9 % of the households, respectively, used improved seed and inorganic fertilizer independently on their plots, while more than half (57 %) of the households jointly adopted both improved seed and inorganic fertilizer. This indicates that more needs to be done to nudge farming households in rural Zimbabwe to use combinations of these technologies for higher yields and welfare gains. In the analysis that follows, we define four categories of households in terms of adoption: (1) *non-adopters* are those that used neither improved seed nor inorganic fertilizer; (2) *improved seed only* are those that used solely improved seed in cultivation; (3) *inorganic fertilizer only* are those that used solely inorganic fertilizer in cultivation; and (4) *joint adopters* are those that used both improved seed and inorganic fertilizer in cultivation.

The outcome variables considered in this paper include productivity of maize, measured as the total quantity of maize harvested per cultivated area (Kg/ha), as well as value of maize harvested per cultivated area (Zimbabwe dollars (ZD/ha)); per capita consumption expenditure (adult equivalent); food share in total consumption expenditure; poverty headcount using the Foster Greer Thorbecke (FGT) (Foster et al., 1984) poverty measure; and food insecurity using the Food and Agriculture

Table 1
Household-level summary statistics and description of variables.

Variable	Definition	Mean	Std
Improved seed	1 if improved seed was planted on at least one plot during the 2016/17 agricultural season	0.82	0.39
Inorganic fertilizer	1 if inorganic fertilizer was used on at least one plot during the agricultural season	0.66	0.47
Improved seed only	1 if improved seed was planted *solely* on at least one plot during the agricultural season	0.25	0.43
Inorganic fertilizer only	1 if inorganic fertilizer was used *solely* on at least one plot during the agricultural season	0.09	0.28
Seed and fertilizer	1 if both improved seed and inorganic fertilizer were used on at least one plot during the agricultural season	0.57	0.50
Per capita consumption	Real monthly consumption expenditure per adult equivalent in Zimbabwe dollars (ZD)	53.26	47.34
Food share	Share of food in household total consumption expenditure	49.36	16.17
Poverty headcount	1 if the per capita consumption expenditure is below the national poverty line	0.79	0.41
Dietary diversity	Number of food groups consumed within the last 24 h prior to the interview day (post- harvest visit)	6.01	1.70
Food security	1 if Food Insecurity Experience Scale (FIES) moderate or severe food insecurity probability during the post-harvest period is <= 0.5	0.85	0.35
Poor food insecure	1 if the household is poor and food insecure	0.13	0.33
Non-poor food secure	1 if the household is non-poor and food secure	0.19	0.39
Maize yield	Total quantity of maize harvest per hectare (Kg/ha)	513	717
Ln maize yield	Logarithm of total quantity of maize harvest per hectare	5.49	1.32
Maize value	Total value of maize harvest per hectare (ZD/ha)	156	312
Maize median price	Median price per kilogram of maize (ZD)	0.30	0.26
Household size	Number of persons in the household	4.94	2.37
Gender	1 if the household head is male	0.64	0.48
Age	Age of the household head in years	50.09	16.98
Education	1 if the household head has completed at least secondary school	0.40	0.49
Wage worker	1 if there is a wage worker in the household	0.14	0.35
Electricity	1 if the household had access to electricity from the national grid	0.45	0.50
Shocks	1 if the household experienced drought, flood or pests shock during the year	0.48	0.50
Erosion	1 if there was erosion problem on at least one plot	0.54	0.50
Mechanization	1 if the household owned any farm implement and machinery	0.74	0.44
Quality soil	1 if the household operated a plot with good quality soil during the agricultural season	0.39	0.49
Irrigation	1 if at least one plot was irrigated during the agricultural season	0.13	0.33
Own land	1 if the household owned any of their cultivated plot during the agricultural season	0.39	0.49
Land area	Total cultivated land holding of the household measured using GPS device (ha)	2.66	3.69
Asset Index	Household asset index constructed using principal component analysis	0.03	1.00
TLU	Total livestock-tropical livestock unit (TLU)	3.20	4.82
Distance input	Distance from homestead to nearest input market (Km)	31.38	54.13
Govt extension	1 if the household had access to government extension services	0.38	0.48
Manicaland	1 if the household is located in the Manicaland province	0.14	0.35
Mash central	1 if the household is located in the Mashonaland Central province	0.12	0.32
Mash east	1 if the household is located in the Mashonaland East province	0.15	0.35
Mash west	1 if the household is located in the Mashonaland West province	0.14	0.34
Mat north	1 if the household is located in the Matabeleland North province	0.10	0.30
Mat south	1 if the household is located in the Matabeleland South province	0.10	0.30
Midlands	1 if the household is located in the Midlands province	0.12	0.32
Masvingo	1 if the household is located in the Masvingo province	0.14	0.34

Organization's (FAO) Food Insecurity Experience Scale (FIES) methodology.[4] We also constructed two composite welfare variables – poor and food insecure, and non-poor and food secure – that examine the impact of adoption on multidimensional welfare.

The average monthly per capita consumption expenditure was about 53.26 ZD,[5] with nearly 50 % of the households' consumption expenditure allocated to food. The poverty headcount rate is about 79 % using the national poverty line of 66 ZD per month. Dietary diversity, measured as the average number of food groups consumed by households during the 7 days prior to the day of interview, was about 6 out of a total of 14 food groups. Using the FIES methodology, the data shows that about 85 % of the sample is food secure, implying that the probability of being moderate or severely food insecure during the post-harvest season is less than 0.5. The data shows further that households harvested, on average, 513 Kg/ha of maize, resulting in about 156 ZD/ha, and consistent with ZimStat (2019).[6] The median price per Kg of maize during the survey period was 0.3 ZD. Household asset index was constructed using principal component analysis (PCA) (Jolliffe and Cadima, 2016; Asfaw, 2016), and includes durables such as television, DVD, radio, bicycle, mobile phone, among others. Following Ahmed (2022), Khonje et al. (2018), Kassie et al. (2015), Teklewold et al. (2013), Ndlovu et al. (2014), and Tesfaye et al. (2020), we also included other household, plot, and geographic variables in the analysis (see Table 1).

4.3. Unconditional mean difference test of salient variables

Before delving into the analytical results, we examine the unconditional descriptive difference in outcome and conditioning variables across adoption categories. The descriptive mean difference test results in Table 2 (see Table A7 for plot-level difference test) show that while adopters in general obtained higher yields and welfare gains, we observe significant variations in observed household characteristics between adopters and non-adopters that could explain their decision to adopt. Adopters of the underlying technologies are generally male-headed households, have spent more years in school (completed at least high school) and have a wage worker present in the household.

We observed that, while all households appear to face similar price for maize, the results show significant differences between adopters and non-adopters in terms of land ownership and size of holding. For instance, joint adopters of improved seed and inorganic fertilizer own

[4] The FIES methodology developed by the FAO uses item-response theory to generate probabilities that households could be moderate or severe, or severe food insecure. The approach uses 8 dichotomous questions on household experience of food insecurity during the 30 days prior to the day of interview. Using the generated probabilities of moderate or severe food insecurity during the post-harvest season, we constructed a dummy variable equal to 1 if the probability of moderate or severe food insecurity is less than 0.5, and 0 otherwise.

[5] Zimbabwe's 2017 Purchasing Power Parity (PPP) for private consumption is 0.61, according to World Bank World Development Indicators (WDI).

[6] Thanks to an anonymous reviewer for suggesting including physical productivity measures.

Table 2
Mean difference test of salient variables.

Variable	Non-adopters	Seed only	Fertilizer only	Seed and fertilizer
Outcomes				
Per capita consumption	51.57	52.66	43.37**	55.30
Food share	54.58	51.58**	48.51***	47.66***
Poverty headcount	0.80	0.80	0.87**	0.77***
Dietary diversity	4.86	5.70***	5.80***	6.37***
Food security	0.66	0.78***	0.87***	0.92***
Poor food insecure	0.27	0.19**	0.12***	0.08***
Non-poor food secure	0.13	0.17*	0.12	0.22***
Maize yield (Kg/ha)	283	309	616***	624***
Ln maize yield	4.91	4.97	5.76***	5.77***
Maize value (ZD/ha)	71	91***	178***	195***
Covariates				
Household size	4.91	4.96	4.68	4.97
Gender	0.56	0.59	0.64**	0.67***
Age	50.52	50.87	45.59***	50.35
Education	0.28	0.34**	0.49***	0.44***
Wage worker	0.05	0.13***	0.17***	0.15***
Electricity	0.36	0.43**	0.37	0.49***
Shocks	0.65	0.57**	0.50***	0.42***
Erosion	0.51	0.56	0.47	0.55
Mechanization	0.60	0.78***	0.52*	0.79***
Quality soil	0.40	0.43	0.28***	0.39
Irrigation	0.04	0.03	0.12***	0.18***
Own land	0.34	0.34	0.32	0.43***
Land area	1.88	2.58***	1.64	2.97***
Asset Index	−0.42	−0.15***	−0.19***	0.21***
TLU	1.91	3.37***	1.84	3.55***
Distance input	4.36	34.45***	1.69*	39.06***
Govt extension	0.19	0.26**	0.35***	0.46***
Maize median price (ZD/Kg)	0.26	0.29***	0.33**	0.30**
Number of observations	188	490	171	1,127

Notes: The test is used to compare the means of salient variables between adopters of each technology and non-adopters (those who did not adopt any technology). ***, ** and * represent significance levels at 1%, 5%, and 10% respectively

Table 3
Determinants of technology adoption – multinomial logit model results.

Variable	Improved seed only	Inorganic fertilizer only	Seed and fertilizer
Household Size	−0.036	0.029	−0.019
	(0.044)	(0.056)	(0.044)
Gender	0.033	−0.047	0.096
	(0.196)	(0.256)	(0.193)
Age	0.004	−0.004	0.010*
	(0.006)	(0.008)	(0.006)
Education	0.275	0.809***	0.631***
	(0.217)	(0.270)	(0.211)
Wage worker	0.642*	1.107**	0.795**
	(0.397)	(0.452)	(0.397)
Electricity	0.007	0.190	0.226
	(0.207)	(0.261)	(0.201)
Shocks	−0.141	−0.768***	−0.758***
	(0.204)	(0.245)	(0.198)
Erosion	0.155	−0.317	0.020
	(0.192)	(0.236)	(0.186)
Mechanization	0.540**	0.080	0.692***
	(0.227)	(0.269)	(0.216)
Quality soil	0.014	−0.565**	−0.279
	(0.196)	(0.247)	(0.190)
Irrigation	−0.186	0.420	0.894**
	(0.510)	(0.509)	(0.438)
Own land	−0.334	0.061	−0.043
	(0.209)	(0.259)	(0.201)
Land area	0.040	−0.022	0.018
	(0.034)	(0.045)	(0.032)
Asset Index	0.192	0.379**	0.450***
	(0.162)	(0.185)	(0.160)
TLU	0.020	0.027	0.037
	(0.038)	(0.044)	(0.039)
Distance input	0.040***	−0.107**	0.040***
	(0.014)	(0.052)	(0.014)
Govt extension	0.242	0.716***	0.864***
	(0.235)	(0.272)	(0.224)
Constant	0.326	−0.450	−0.233
	(0.546)	(0.701)	(0.526)
Joint sign. of regional dummies		327.30***	
Joint sign. of instruments		44.14***	
Wald test			588.05***
Pseudo R^2			0.2598
Number of observations			1,976

Notes: Robust standard errors in parenthesis; non-adoption is the reference category. ***, ** and * represent significance levels at 1%, 5%, and 10% respectively

substantially more agricultural lands and have larger farm sizes than non-adopters. Differences also exist between adopters and non-adopters in terms of their asset and livestock ownership, with adopters generally having significantly larger asset index and livestock units (TLU) than their non-adopting counterparts. These differences in observed characteristics of households could contribute to their self-selection into an adoption category, and thus, the resulting productivity and welfare gains. In what follows, we control for these observed factors, as well as other unobserved heterogeneity to decipher the actual welfare effects of the technologies.

5. Econometric results

5.1. Determinants of adoption – Multinomial logit model estimation

In Table 3, the MNLR results of the factors influencing the adoption of the underlying technologies are presented (see Table A8 for plot-level determinants of adoption). The base category is non-adoption of either technologies. The model fits the data reasonably well as the Wald test shows that the null hypothesis of all covariates coefficients being jointly equal to zero is rejected ($\chi^2(72) = 588.05$, $p = 0.000$). The joint test results for the provincial dummies indicate that differences in government development policies as well as variations in climatic conditions in these regions may significantly contribute to the use of improved seed and inorganic fertilizer, as well as their combined use in production.

The table indicates that household demographic and farm level characteristics, as well as geographic factors significantly influence the decision to adopt the technologies. Specifically, the adoption of improved seed is facilitated by households' ownership of farm mechanization and presence of a wage worker in the household. Similarly, households' decisions to adopt inorganic fertilizer is enhanced by education of the household head and wage employment, as well as the soil quality of at least one cultivated plot. Households are less likely to apply inorganic fertilizer to plots they perceive the quality to be good. The results also show that households that have experienced shocks (including drought, flood, or pests) are less likely to invest in the use of inorganic fertilizer.

The age and years of education of the household head, as well as presence of a wage employee in the household are vital drivers of households' decision to jointly use the technologies. In addition, the use of both technologies' hinges on households' ownership of farm mechanization and irrigation facilities. Likewise, households with large asset index have a higher tendency to jointly use these practices on their plots compared to those otherwise. We also observe the relevance of agricultural extension services delivery in fostering joint adoption.

5.2. Impact of adoption on farm-level productivity and household welfare

The MESR model results of the impact of adoption on farm-level productivity (maize yield and value of harvest) and household welfare (consumption expenditure, food share in total expenditure, dietary diversity, poverty, food security, and composite welfare) are presented in Tables 4 – 6. For each adoption-outcome combination, results for both actual (adopters) and counterfactual (non-adopters) as well as the conditional and unconditional average treatment effects are presented. The second stage regression results for the outcome variables are presented in Tables A2–A5 but are not discussed here due to space. The productivity and welfare effects of adoption were estimated using predicted outcome values from the MESR model.

5.2.1. Plot-level impact of adoption – Maize productivity[7]

Before delving into the household-level impact of adoption, it is important to understand the farm-level mechanism through which adoption impacts household welfare. In Table 4, we examine the impact of the technologies on maize productivity at the plot-level. The unconditional results indicates that the adoption of the underlying technologies in general increases maize productivity, both in physical and monetary terms. Plot-level maize output per hectare increases by 590 Kg/ha (56 %) for the joint use of improved seed and inorganic fertilizer, resulting in about 201 ZD/ha gain in revenue. Notwithstanding, these do not provide a true picture of the impact of the technologies at the plot-level since they do not account for selection bias emanating from observed and unobserved factors. Thus, drawing conclusions and policy implications from these unconditional results could be misleading.

Table 4
Plot-level impact of adoption on productivity – MESR with Mundlak's procedure.

	Outcome variable	Technology type	Adopters	Non-adopter	Treatment effect
Unconditional average treatment effects	Ln (maize yield)	Seed only	6.10	5.94	0.16***
		Fertilizer only	6.35	5.94	0.40***
		Seed and fertilizer	6.50	5.94	0.56***
	Maize yield (Kg/ha)	Seed only	937	792	145***
		Fertilizer only	1,188	792	396***
		Seed and fertilizer	1,382	792	590***
	Maize value (ZD/ha)	Seed only	266	228	38***
		Fertilizer only	356	228	129***
		Seed and fertilizer	429	228	201***
Conditional average treatment effects	Ln (maize yield)	Seed only	5.97	5.79	0.17***
		Fertilizer only	6.66	6.08	0.58***
		Seed and fertilizer	6.66	6.01	0.65***
	Maize yield (Kg/ha)	Seed only	837	692	145***
		Fertilizer only	1,478	885	593***
		Seed and fertilizer	1,535	838	697***
	Maize value (ZD/ha)	Seed only	253	215	39***
		Fertilizer only	410	239	171***
		Seed and fertilizer	510	234	276***

Notes: Conditional results control for both observed and unobserved heterogeneity, while the unconditional controls for neither. ***, ** and * represent significance levels at 1%, 5%, and 10% respectively

The second half of Table 4 presents the plot-level productivity effects of adoption after controlling for selection bias. The results show that the adoption of the technologies in general increases maize productivity. The maize-productivity effect of improved seed adoption is about 145 Kg/ha (about 17 %), while that of inorganic fertilizer is 593 Kg/ha (about 58 %). The joint application of improved seed and inorganic fertilizer during the production season increases maize physical yield by about 697Kg/ha (65 %), compared to those that did not adopt any technology. This result is consistent with Ahmed (2022) who found joint use of improved seed and inorganic fertilizer to improve maize yields in Ethiopia. Fig. 1 shows the kernel density function of the predicted yield values following the correction for observed and unobserved heterogeneities. We observe that the kernel density of maize lies to the right for inorganic fertilizer sole use, as well as the joint adoption of both technologies. The productivity results show that households would have obtained lower yields had they not used these technologies in production, especially joint application. These results are, in general, consistent with other empirical works, including Ahmed (2022), Khonje et al. (2018), Kassie et al. (2015), Teklewold et al. (2013), Ndlovu et al. (2014), and Tesfaye et al. (2020).

5.2.2. Consumption and nutrition effects of adoption

The impact of adoption on household consumption and nutrition are presented in Table 5. From the conditional results, we see that the adoption of the technologies appears to marginally reduce household consumption expenditure per-capita and the share of expenditure allocated to food consumption. The kernel density function in Fig. 2 also provides further insight; the kernel density of consumption of non-adopters lie to the right. This could be attributed to the fact that maize is the main staple in Zimbabwe (Murendo et al., 2022), and thus, improved technologies that increase production and farm income could lead to households re-allocating resources from food consumption to other needs. That notwithstanding, adopters tend to eat more diverse foods, with the number of food groups consumed increasing by 9 % and 12 % for independent use of improved seed and inorganic fertilizer, respectively, and 23 % for joint adoption.

5.2.3. Poverty and food security effects

The poverty and food security effects of adoption, estimated from the METE procedure are presented in Table 6. The conditional results show that the use of improved seed reduces the probability of a household becoming poor, while the reverse is observed for the independent use of inorganic fertilizer. The joint use of the technologies has no poverty reduction effect. These results follow from the consumption expenditure results and discussions presented earlier. The adoption of both technologies significantly improves household food security; probability of being food secure increases by about 21 percentage points.

The results of the composite welfare measures from Table 6 show that households' adoption of improved seed significantly increases the probability of being non-poor and food secure; the share of non-poor and food secure households increases by 20 percentage points. The independent adoption of inorganic fertilizer does not have any significant effect on improving multidimensional welfare in rural Zimbabwe. The joint use of improved seed and inorganic fertilizer, however, reduces the probability of a household becoming poor and food insecure by 13 percentage points. Thus, the results in general show that the adoption of the technologies improves the welfare of poor and food insecure, and non-poor and food secure households, though poor and food insecure households tend to benefit more from joint adoption.

[7] Thanks to an anonymous reviewer for recommending this plot-level analysis. We follow Mundlak (1978) approach to include mean of plot-varying covariates.

Table 5
Household-level impact of adoption on welfare – continuous outcome variables.

	Outcome variable	Technology type	Adopters	Non-adopter	Treatment effect
Unconditional					
	Ln (consumption)	Seed only	3.70	3.80	−0.10***
		Fertilizer only	3.86	3.80	0.06***
		Seed and fertilizer	3.76	3.80	−0.04***
	Food share (percent)	Seed only	49.93	52.70	−2.77***
		Fertilizer only	51.63	52.70	−1.07***
		Seed and fertilizer	48.74	52.70	−3.96***
	Ln (dietary diversity)	Seed only	1.74	1.59	0.15***
		Fertilizer only	1.94	1.59	0.36***
		Seed and fertilizer	1.78	1.59	0.19***
Conditional					
	Ln (consumption)	Seed only	3.77	3.88	−0.11***
		Fertilizer only	3.63	3.64	0.00
		Seed and fertilizer	3.79	3.80	−0.01*
	Food share (percent)	Seed only	51.53	53.01	−1.48***
		Fertilizer only	48.51	53.97	−5.46***
		Seed and fertilizer	47.66	52.06	−4.40***
	Ln (dietary diversity)	Seed only	1.70	1.61	0.09***
		Fertilizer only	1.72	1.60	0.12***
		Seed and fertilizer	1.82	1.59	0.23***

Notes: ***, ** and * represent significance levels at 1%, 5%, and 10% respectively

Table 6
Household-level impact of adoption on welfare – binary outcome variables.

Outcome variable	Technology type	Exogenous		–	Endogenous	
		Treatment effect	Std. error		Treatment effect	Std. error
Poverty headcount	Seed only	0.04	0.03		−0.16***	0.05
	Fertilizer only	0.11***	0.04		0.15**	0.07
	Seed and fertilizer	0.05*	0.03		0.02	0.04
Food security	Seed only	0.08***	0.03		0.09**	0.05
	Fertilizer only	0.11***	0.04		0.13*	0.08
	Seed and fertilizer	0.13***	0.03		0.21***	0.05
Poor & food insecure	Seed only	−0.04	0.03		−0.06	0.05
	Fertilizer only	−0.06*	0.03		0.06	0.06
	Seed and fertilizer	−0.07***	0.03		−0.13***	0.04
Non-poor & food secure	Seed only	0.00	0.03		0.20***	0.05
	Fertilizer only	−0.06	0.04		−0.07	0.04
	Seed and fertilizer	0.01	0.03		0.04	0.04

Notes: ***, ** and * represent significance levels at 1%, 5%, and 10% respectively

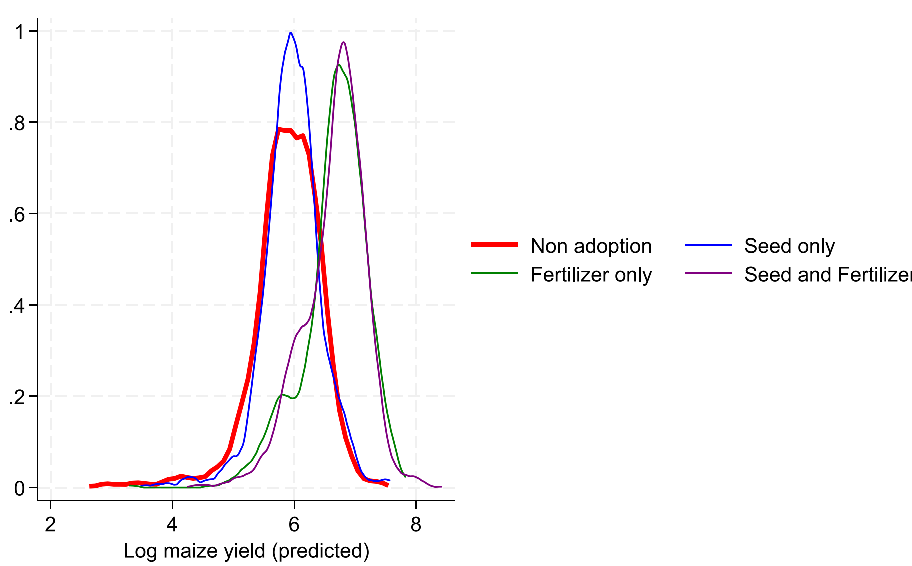

Fig. 1. Kernel density distribution of plot-level maize yield by adoption status.

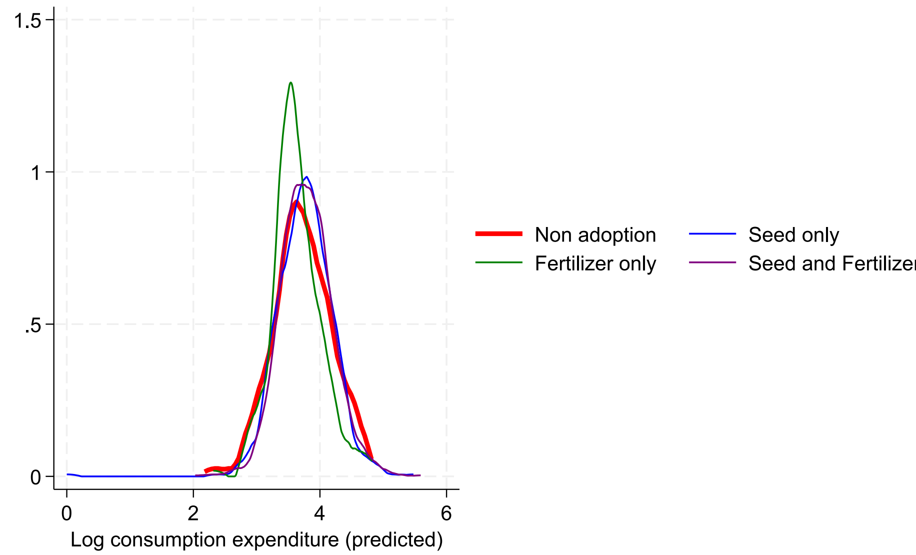

Fig. 2. Kernel density distribution of consumption expenditure by adoption status.

5.2.4. *Robustness check with PSM and IV regression procedures*

As a robustness check, the PSM model that controls for observed household characteristics, as well as the IV regression procedure were estimated (Table 7 and 8, respectively). The PSM and the IV regression results are in general consistent with those of the MESR and METE in terms of statistical significance and the direction of impact. These robustness check results also show in general that the highest gain is in the use of both technologies, corroborating the findings from the MESR and METE.

Table 7
Robustness checks on household-level welfare effects of adoption using PSM.

Outcome variable	Technology type	Treatment effect	Std. Error
Ln (consumption)	Seed only	−0.07	0.05
	Fertilizer only	−0.22**	0.11
	Seed and fertilizer	−0.10	0.21
Food share (percent)	Seed only	−1.58	1.68
	Fertilizer only	−6.80***	2.26
	Seed and fertilizer	−3.44	2.77
Ln (dietary diversity)	Seed only	0.45**	0.18
	Fertilizer only	0.96**	0.49
	Seed and fertilizer	1.01***	0.16
Poverty headcount	Seed only	0.11***	0.04
	Fertilizer only	0.21*	0.11
	Seed and fertilizer	0.13	0.16
Food security	Seed only	0.07	0.05
	Fertilizer only	0.05	0.05
	Seed and fertilizer	0.09**	0.04
Poor & food insecure	Seed only	0.01	0.04
	Fertilizer only	−0.03	0.05
	Seed and fertilizer	−0.05	0.03
Non-poor & food secure	Seed only	−0.03	0.05
	Fertilizer only	−0.19	0.12
	Seed and fertilizer	−0.09	0.16
Ln (maize yield)	Seed only	0.04	0.14
	Fertilizer only	0.44	0.38
	Seed and fertilizer	1.11***	0.10
Maize yield (Kg/ha)	Seed only	8.20***	50.53
	Fertilizer only	218***	83.71
	Seed and fertilizer	370***	27.95
Maize value (ZD/ha)	Seed only	6.02	14.08
	Fertilizer only	72***	26.89
	Seed and fertilizer	132***	13.84

Notes: ***, ** and * represent significance levels at 1%, 5%, and 10% respectively

Table 8
Robustness checks on welfare effects of adoption using IV.

Outcome variable	Technology type	Treatment effect	Std. error
Ln (consumption)	Seed only	0.23	0.22
	Fertilizer only	−0.05	0.29
	Seed and fertilizer	0.11	0.17
Food share (percent)	Seed only	9.21	7.33
	Fertilizer only	−0.95	9.96
	Seed and fertilizer	−1.71	5.42
Ln (dietary diversity)	Seed only	−0.17	0.76
	Fertilizer only	0.34	1.01
	Seed and fertilizer	2.35***	0.55
Poverty headcount	Seed only	−0.06	0.16
	Fertilizer only	0.44*	0.23
	Seed and fertilizer	−0.11	0.13
Food security	Seed only	0.03	0.20
	Fertilizer only	0.37	0.28
	Seed and fertilizer	0.37***	0.11
Poor & food insecure	Seed only	−0.05	0.18
	Fertilizer only	−0.16	0.25
	Seed and fertilizer	−0.31***	0.10
Non-poor & food secure	Seed only	0.04	0.15
	Fertilizer only	−0.23	0.20
	Seed and fertilizer	0.17	0.13
Ln (maize yield)	Seed only	0.65	0.63
	Fertilizer only	1.82**	0.87
	Seed and fertilizer	1.77***	0.48
Maize yield (Kg/ha)	Seed only	77	222
	Fertilizer only	624***	337
	Seed and fertilizer	625***	258
Maize value (ZD/ha)	Seed only	40	62
	Fertilizer only	96	116
	Seed and fertilizer	452***	128

Notes: ***, ** and * represent significance levels at 1%, 5%, and 10% respectively

6. Conclusions

The adoption and welfare effects of improved and sustainable agricultural practices have received much attention in the development economics literature. In the case of Zimbabwe, however, empirical studies in this area are limited. This paper uses nationally representative micro-data to examine the productivity and welfare effects (with a focus on food security and poverty) of improved seed and inorganic fertilizer, and their joint adoption in rural Zimbabwe. We employ the MESR and METE models that control for both observed and unobserved heterogeneity. The PSM and IV regression approaches were used as robustness checks. The welfare variables considered in this study are consumption expenditure, food share in total consumption expenditure, dietary diversity, poverty headcount, food security, and composite/multidimensional welfare, while productivity focused on maize yield (Kg/ha) and value of output per hectare.

The results from the multinomial logit regression model indicate that households who own mechanization, and have a wage worker present in the household are more likely to adopt improved seed solely in production. The independent use of inorganic fertilizer is facilitated by years of education of the household head, and the quality of soil on plots for production. The joint adoption of improved seed and inorganic fertilizer hinges on education, salary work, irrigation facilities, and household asset ownership. We also observed that households that experienced shocks in the form of pest, drought, or flood are less likely to jointly adopt the technologies.

After controlling for observed and unobserved heterogeneity, the results show that, in general, the adoption of improved seed and inorganic fertilizer, as well as their joint usage, have productivity and welfare enhancing effects on rural farming households in Zimbabwe. We observe that households that adopt both technologies experienced higher productivity and welfare gains than those using a single practice in production. This implies that efforts to nudge farmers to use combination of these technologies are vital at ensuring they reap the full benefit from adoption. Adoption of improved seed increases maize yields by about 17 %, while at the same time reducing the share of households that are poor by 16 percentage points. Joint usage results in maize productivity gain of about 65 %, resulting in increased food security and dietary diversity, as well as a reduction in the share of household expenditure devoted to food consumption.

The above results imply that as the government continues to implement various interventions in the agriculture sector, it is important to focus on nudging smallholder farming households to adopt productivity and welfare-enhancing agricultural technologies, and their joint usage. These could be done by resourcing agricultural extension agents and boosting their expertise to educate smallholder farmers on the benefits of these technologies. This is particularly important for the joint adoption of both improved seed and inorganic fertilizer as the two, are found to be complimentary to each other for maximum yield and welfare gains.

Notwithstanding these, the study is limited in two ways. First the data used, though nationally representative, is cross-sectional, that does not allow for conducting rigorous panel analysis to track dynamics in these indicators and control for household and time fixed effects. Second, given that we used multi-topic household survey data, definition of variables used in the study is limited to how these variables were measured in the survey.

CRediT authorship contribution statement

Akuffo Amankwah: Writing – review & editing, Writing – original draft, Validation, Software, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Tendai Gwatidzo:** Writing – review & editing, Writing – original draft, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix

Table A1
Simple falsification test of excluded instruments.

Outcome variable	Technology type	F- stat.	P-value
Ln (consumption)	Non-adoption	0.20	0.816
	Seed only	2.15	0.118
	Fertilizer only	1.09	0.337
	Seed and fertilizer	0.95	0.388
Food share (percent)	Non-adoption	0.82	0.442
	Seed only	1.97	0.141
	Fertilizer only	0.07	0.931
	Seed and fertilizer	0.31	0.735
Ln (dietary diversity)	Non-adoption	0.53	0.588
	Seed only	3.70	0.025
	Fertilizer only	2.16	0.119
	Seed and fertilizer	3.37	0.035
Poverty headcount	Non-adoption	0.88	0.418
	Seed only	0.21	0.808
	Fertilizer only	0.75	0.475
	Seed and fertilizer	2.25	0.106
Food security	Non-adoption	1.04	0.355
	Seed only	0.75	0.472
	Fertilizer only	0.34	0.715
	Seed and fertilizer	3.49	0.031
Poor & food insecure	Non-adoption	0.45	0.639
	Seed only	0.87	0.420
	Fertilizer only	0.75	0.473
	Seed and fertilizer	3.97	0.019
Non-poor & food secure	Non-adoption	0.30	0.744
	Seed only	0.10	0.909
	Fertilizer only	0.34	0.714
	Seed and fertilizer	2.02	0.134
Ln (maize yield)	Non-adoption	1.43	0.241
	Seed only	2.54	0.080
	Fertilizer only	1.15	0.321
	Seed and fertilizer	3.75	0.024
Maize yield (Kg/ha)	Non-adoption	1.20	0.303

(*continued on next page*)

Table A1 (*continued*)

Outcome variable	Technology type	F- stat.	P-value
	Seed only	0.94	0.390
	Fertilizer only	0.29	0.747
	Seed and fertilizer	4.45	0.012
Maize value (ZD/ha)	Non-adoption	1.78	0.172
	Seed only	0.76	0.470
	Fertilizer only	0.46	0.630
	Seed and fertilizer	5.14	0.006

Table A2
Estimation of the main equation for *Ln consumption* (second stage of MESR).

Variable	Non-adoption	Seed only	Fertilizer only	Seed and fertilizer
Household size	−0.154***	−0.147***	−0.156***	−0.137***
	(0.019)	(0.009)	(0.019)	(0.007)
Gender	0.079	−0.009	−0.026	−0.052
	(0.079)	(0.044)	(0.073)	(0.037)
Age	0.002	0.003*	0.002	0.002**
	(0.003)	(0.001)	(0.003)	(0.001)
Education	−0.026	0.018	−0.080	−0.014
	(0.100)	(0.057)	(0.074)	(0.038)
Wage worker	0.041	0.181**	0.179*	0.169***
	(0.216)	(0.076)	(0.098)	(0.042)
Electricity	0.101	0.131***	0.141**	0.067**
	(0.105)	(0.043)	(0.070)	(0.032)
Shocks	−0.170	−0.099*	0.044	−0.064*
	(0.115)	(0.055)	(0.081)	(0.034)
Erosion	−0.025	0.012	−0.071	0.014
	(0.092)	(0.043)	(0.064)	(0.031)
Mechanization	−0.188	−0.047	0.016	−0.015
	(0.119)	(0.056)	(0.084)	(0.035)
Quality soil	−0.104	−0.036	0.080	−0.007
	(0.103)	(0.047)	(0.070)	(0.028)
Irrigation	0.343	0.204	−0.221*	0.040
	(0.283)	(0.170)	(0.116)	(0.058)
Own land	−0.051	0.020	−0.074	0.012
	(0.083)	(0.059)	(0.084)	(0.031)
Land area	0.000	−0.003	0.003	−0.000
	(0.018)	(0.007)	(0.018)	(0.004)
Asset Index	0.261***	0.180***	0.160***	0.178***
	(0.089)	(0.038)	(0.049)	(0.017)
TLU	0.001	0.016**	−0.014	0.009***
	(0.014)	(0.006)	(0.014)	(0.003)
σ^2	0.647	0.168**	0.259	0.296***
	(1.236)	(0.081)	(0.645)	(0.086)
λ_1		0.210	0.967	0.853**
		(0.452)	(0.818)	(0.413)
λ_2	−0.984**		−0.385	−0.578
	(0.451)		(0.894)	(0.360)
λ_3	0.458	−0.057		−0.156
	(0.580)	(0.533)		(0.281)
λ_4	0.529	0.245	−0.627	
	(0.575)	(0.476)	(0.509)	
Constant	4.677***	4.624***	4.600***	4.486***
	(0.291)	(0.164)	(0.355)	(0.184)
Regional dummies	Yes	Yes	Yes	Yes
Number of observations	188	490	171	1,127

Notes: Robust standard errors in parenthesis; non-adoption is the reference category. ***, ** and * represent significance levels at 1 %, 5 %, and 10 % respectively.

Table A3
Estimation of the main equation for *food share* in total consumption (second stage of MESR).

Variable	Non-adoption	Seed only	Fertilizer only	Seed and fertilizer
Household size	0.213	0.646**	0.491	1.195***
	(0.476)	(0.299)	(0.799)	(0.199)
Gender	3.144	1.075	0.505	0.462
	(3.116)	(1.372)	(3.025)	(0.992)
Age	−0.070	−0.051	−0.133	0.037
	(0.091)	(0.046)	(0.116)	(0.039)
Education	0.459	2.122	−0.016	−0.475

(*continued on next page*)

Table A3 (*continued*)

Variable	Non-adoption	Seed only	Fertilizer only	Seed and fertilizer
	(3.789)	(1.660)	(3.759)	(1.198)
Wage worker	3.975	−6.239**	−10.397**	−4.850***
	(6.762)	(2.673)	(4.469)	(1.322)
Electricity	1.737	−2.673*	−1.948	−1.814*
	(2.886)	(1.463)	(3.370)	(1.048)
Shocks	0.283	2.873	1.243	−0.540
	(3.732)	(2.025)	(3.360)	(1.201)
Erosion	−2.085	−1.266	1.062	3.126***
	(2.981)	(1.578)	(3.361)	(0.948)
Mechanization	−1.077	−2.759	1.551	−0.513
	(3.835)	(1.988)	(4.585)	(1.293)
Quality soil	−1.112	−0.717	−2.754	1.003
	(3.149)	(1.678)	(3.304)	(1.084)
Irrigation	0.926	−6.987	1.361	−3.039*
	(11.134)	(5.792)	(4.486)	(1.595)
Own land	3.210	0.710	−1.590	0.056
	(3.385)	(1.565)	(3.670)	(1.074)
Land area	1.228**	0.155	0.132	−0.045
	(0.590)	(0.250)	(0.675)	(0.134)
Asset Index	2.041	−3.784***	−3.492**	−3.000***
	(2.988)	(1.121)	(1.776)	(0.576)
TLU	−0.569	0.640***	0.038	0.149
	(0.512)	(0.179)	(0.585)	(0.116)
σ^2	373.240	222.454***	303.791	236.241***
	(960.401)	(68.370)	(2,956.419)	(57.467)
λ_1		−0.342	0.351	0.195
		(0.452)	(0.812)	(0.512)
λ_2	−0.723		−0.820	−0.327
	(0.577)		(0.899)	(0.403)
λ_3	0.293	0.399		−0.121
	(0.599)	(0.546)		(0.283)
λ_4	0.558	−0.191	0.441	
	(0.719)	(0.345)	(0.573)	
Constant	55.122***	49.506***	57.596***	39.702***
	(7.547)	(4.304)	(13.319)	(6.285)
Regional dummies	Yes	Yes	Yes	Yes
Number of observations	188	490	171	1,127

Notes: Robust standard errors in parenthesis; non-adoption is the reference category. ***, ** and * represent significance levels at 1 %, 5 %, and 10 % respectively.

Table A4
Estimation of the main equation for *dietary diversity* (second stage of MESR).

Variable	Non-adoption	Seed only	Fertilizer only	Seed and fertilizer
Household size	−0.000	−0.012**	−0.015	−0.012***
	(0.020)	(0.006)	(0.015)	(0.003)
Gender	0.026	0.004	−0.029	0.001
	(0.075)	(0.035)	(0.057)	(0.018)
Age	0.007***	0.000	−0.000	0.001
	(0.003)	(0.001)	(0.002)	(0.001)
Education	0.136	−0.010	0.041	0.030
	(0.103)	(0.038)	(0.063)	(0.020)
Wage worker	−0.166	−0.061	0.061	0.020
	(0.197)	(0.046)	(0.074)	(0.026)
Electricity	0.202***	0.043	0.027	0.033*
	(0.076)	(0.031)	(0.058)	(0.019)
Shocks	−0.188*	−0.045	−0.091	−0.014
	(0.110)	(0.043)	(0.065)	(0.021)
Erosion	0.046	−0.082***	−0.052	−0.004
	(0.075)	(0.030)	(0.057)	(0.018)
Mechanization	0.241***	0.051	0.078	0.007
	(0.091)	(0.034)	(0.065)	(0.026)
Quality soil	−0.055	−0.011	0.020	0.015
	(0.093)	(0.034)	(0.059)	(0.017)
Irrigation	0.410	0.018	−0.037	0.011
	(0.268)	(0.118)	(0.100)	(0.028)
Own land	0.288***	0.011	0.029	0.017
	(0.086)	(0.036)	(0.074)	(0.018)
Land area	−0.027	0.002	−0.003	0.003
	(0.018)	(0.004)	(0.014)	(0.002)
Asset Index	0.055	0.079***	0.036	0.058***
	(0.070)	(0.024)	(0.047)	(0.008)
TLU	0.010	0.007**	0.007	0.006***

(*continued on next page*)

Table A4 (*continued*)

Variable	Non-adoption	Seed only	Fertilizer only	Seed and fertilizer
	(0.010)	(0.003)	(0.009)	(0.002)
σ^2	2.843	0.101**	0.866	0.082***
	(1.803)	(0.049)	(0.837)	(0.028)
λ_1		0.638	0.966	0.874**
		(0.400)	(0.688)	(0.404)
λ_2	−0.720**		−1.225*	−0.586
	(0.299)		(0.741)	(0.386)
λ_3	−0.466	−0.732*		−0.141
	(0.383)	(0.433)		(0.245)
λ_4	1.113***	0.103	0.210	
	(0.133)	(0.401)	(0.485)	
Constant	1.001***	1.887***	1.469***	1.789***
	(0.238)	(0.111)	(0.226)	(0.089)
Regional dummies	Yes	Yes	Yes	Yes
Number of observations	188	490	171	1,127

Notes: Robust standard errors in parenthesis; non-adoption is the reference category. ***, ** and * represent significance levels at 1 %, 5 %, and 10 % respectively.

Table A5
Estimation of the main equation for plot-level ln *maize yield* (second stage of MESR).

Variable	Non-adoption	Seed only	Fertilizer only	Seed and fertilizer
Household size	−0.002	−0.044***	−0.071***	−0.032**
	(0.022)	(0.016)	(0.025)	(0.014)
Gender	−0.069	0.056	−0.120	−0.135**
	(0.111)	(0.078)	(0.109)	(0.067)
Age	−0.004	−0.000	−0.000	0.001
	(0.003)	(0.002)	(0.003)	(0.002)
Education	−0.204*	−0.252***	0.034	0.108
	(0.109)	(0.083)	(0.106)	(0.093)
Wage worker	−0.305*	0.119	0.099	0.257**
	(0.185)	(0.109)	(0.156)	(0.103)
Electricity	0.194*	0.028	0.153	0.067
	(0.108)	(0.073)	(0.109)	(0.071)
Shocks	0.093	0.213**	0.110	0.135
	(0.098)	(0.088)	(0.112)	(0.086)
Erosion	−0.252	−0.229*	0.124	0.032
	(0.164)	(0.135)	(0.170)	(0.118)
Mechanization	−0.150	0.135	−0.089	0.130
	(0.119)	(0.123)	(0.129)	(0.105)
Quality soil	0.062	−0.079	0.258	0.289
	(0.222)	(0.193)	(0.250)	(0.178)
Irrigation	0.701	−0.240	−0.345	−0.153
	(0.565)	(0.450)	(0.288)	(0.185)
Own land	−0.440	0.244	0.919	0.124
	(1.581)	(0.555)	(1.176)	(0.290)
Land area	−0.739***	−0.617***	−1.292***	−0.593***
	(0.148)	(0.134)	(0.337)	(0.077)
Asset Index	−0.084	0.028	0.013	−0.019
	(0.098)	(0.050)	(0.059)	(0.039)
TLU	0.034***	−0.005	0.009	0.002
	(0.013)	(0.010)	(0.011)	(0.007)
Hired labor	−0.511**	−0.384*	0.003	−0.087
	(0.226)	(0.218)	(0.234)	(0.122)
σ^2	8.346**	2.129**	4.725	2.948*
	(3.761)	(0.834)	(2.926)	(1.563)
λ_1		0.443	−0.150	−0.532
		(0.295)	(0.305)	(0.488)
λ_2	0.582***		0.965***	0.949***
	(0.107)		(0.223)	(0.219)
λ_3	0.556***	0.059		−0.061
	(0.212)	(0.494)		(0.395)
λ_4	−1.039***	−0.640*	−0.757***	
	(0.134)	(0.341)	(0.226)	
Constant	6.472***	5.754***	6.832***	7.356***
	(0.433)	(0.338)	(0.384)	(0.462)
Regional dummies	Yes	Yes	Yes	Yes
Mean of plot-varying covariates	Yes	Yes	Yes	Yes
Number of observations	835	1,262	737	1,904

Notes: Robust standard errors in parenthesis; non-adoption is the reference category. ***, ** and * represent significance levels at 1 %, 5 %, and 10 % respectively.

Table A6
Plot-level summary statistics and description of variables.

Variable	Definition	Mean	Std	N
Improved seed	1 if improved seed was planted on plot during the 2016/17 agricultural season	0.67	0.47	4,738
Inorganic fertilizer	1 if inorganic fertilizer was used on plot during the agricultural season	0.56	0.50	4,738
Improved seed *only*	1 if improved seed was planted *solely* on plot during the agricultural season	0.27	0.44	4,738
Inorganic fertilizer *only*	1 if inorganic fertilizer was used *solely* on plot during the agricultural season	0.16	0.36	4,738
Seed and fertilizer	1 if both improved seed and inorganic fertilizer was used on plot during the agricultural season	0.40	0.49	4,738
Maize yield	Total quantity of maize harvest per hectare (Kg/ha)	1203	1793	4,738
Ln maize yield	Logarithm of total quantity of maize harvest per hectare	6.34	1.33	4,738
Maize value	Total value of maize harvest per hectare (ZD/ha)	375	689	4,738
Maize price	Median price per kilogram of maize (ZD)	0.32	0.30	4,738
Household size	Number of persons in the household	5.05	2.43	4,738
Gender	1 if the household head is male	0.64	0.48	4,738
Age	Age of the household head in years	51.40	16.90	4,738
Education	1 if the household head has completed secondary school	0.39	0.49	4,738
Wage worker	1 if there is a wage worker in the household	0.14	0.34	4,738
Electricity	1 if the household had access to electricity from the national grid	0.46	0.50	4,738
Shocks	1 if the household experienced drought, flood, or pests shock during the year	0.46	0.50	4,738
Erosion	1 if there was erosion problem on at least one plot	0.31	0.46	4,738
Mechanization	1 if the household owned farm implements or machinery any during the agricultural season	0.78	0.41	4,738
Quality soil	1 if plot has good quality soil	0.30	0.46	4,738
Irrigation	1 if plot was irrigated during the agricultural season	0.04	0.20	4,738
Owned land	1 if the plot was owned by the household	0.41	0.49	4,738
Land area	Total land holding of the household (ha)	0.46	0.76	4,738
Asset Index	Household asset index constructed using principal component analysis	0.09	1.02	4,738
TLU	Total livestock-tropical livestock unit (TLU)	3.62	4.98	4,738
Distance input	Distance from homestead to nearest input market (Km)	32.73	52.54	4,738
Govt extension	1 if the household had access to government extension services	0.43	0.50	4,738
Hired labor	1 if the hired labor was used on plot during the season	0.19	0.39	4,738

Table A7
Plot-level mean difference test of salient covariates.

Variable	Non-adopter	Seed only	Fertilizer only	Seed and fertilizer
Productivity measures				
Maize yield (Kg/ha)	757	837*	1,478***	1,535***
Ln (maize yield)	5.89	5.97	6.66***	6.66***
Maize value (ZD/ha)	223	253*	410***	510***
Covariates				
Maize median price (ZD/Kg)	0.29	0.31*	0.31	0.33***
Household size	5.09	5.18	4.74***	5.06
Gender	0.65	**0.61****	0.66	0.65
Age	50.44	52.34***	49.17*	52.07***
Education	0.35	0.37	0.40**	0.43***
Wage worker	0.08	0.14***	0.12***	0.16***
Electricity	0.40	0.49***	0.43**	0.48***
Shocks	0.64	0.50***	0.46***	0.37***
Erosion	0.34	0.35	0.26***	0.29**
Mechanization	0.71	0.82***	0.70	0.82***
Quality soil	0.31	0.33	0.23***	0.30
Irrigation	0.02	0.02	0.06***	0.06***
Own land	0.41	0.40	0.38	0.42
Land area	0.44	0.50**	0.35***	0.49**
Asset Index	−0.24	0.06***	−0.01***	0.30***
TLU	2.86	4.08***	2.75	3.99***
Distance input	17.91	36.73***	27.46***	38.61***
Govt extension	0.31	0.35**	0.46***	0.54***
Hired labor	0.10	0.16***	0.17***	0.26***

Notes: The test is used to compare the means of salient variables between adopters of each technology and non-adopters (those who did not adopt any technology). ***, ** and * represent significance levels at 1 %, 5 %, and 10 % respectively.

Table A8
Plot-level determinants of technology adoption – multinomial logit model results.

Variable	Improved seed only	Inorganic fertilizer only	Seed and fertilizer
Household size	0.001	−0.039	0.009
	(0.020)	(0.025)	(0.021)
Gender	−0.220**	−0.062	−0.189*
	(0.102)	(0.123)	(0.102)
Age	0.002	−0.001	0.009***
	(0.003)	(0.004)	(0.003)

(*continued on next page*)

Table A8 (*continued*)

Variable	Improved seed only	Inorganic fertilizer only	Seed and fertilizer
Education	0.014	−0.012	0.262**
	(0.111)	(0.131)	(0.110)
Wage worker	0.463***	0.338*	0.584***
	(0.167)	(0.189)	(0.164)
Electricity	0.098	0.150	0.036
	(0.099)	(0.116)	(0.098)
Shocks	−0.384***	−0.576***	−0.859***
	(0.100)	(0.115)	(0.098)
Erosion	0.186	−0.143	0.168
	(0.188)	(0.220)	(0.183)
Mechanization	0.305**	0.095	0.392***
	(0.124)	(0.134)	(0.117)
Quality soil	0.128	0.015	−0.115
	(0.273)	(0.334)	(0.275)
Irrigation	−1.035**	−0.331	−0.768*
	(0.514)	(0.484)	(0.465)
Own land	0.783	0.505	−0.728
	(0.748)	(0.512)	(0.564)
Land area	0.216	0.301*	0.555***
	(0.194)	(0.178)	(0.188)
Asset Index	0.198***	0.252***	0.377***
	(0.068)	(0.076)	(0.065)
TLU	0.010	0.002	0.015
	(0.012)	(0.015)	(0.012)
Hired labor	0.113	0.205	0.424*
	(0.256)	(0.279)	(0.244)
Distance input	0.008***	0.004**	0.007***
	(0.002)	(0.002)	(0.002)
Govt extension	0.118	0.394***	0.619***
	(0.105)	(0.117)	(0.099)
Constant	0.397	−0.916***	−0.665**
	(0.271)	(0.351)	(0.283)
Joint sign. of regional dummies		724.95***	
Joint sign. of instruments		84.50***	
Wald test			1304.51***
Pseudo R^2			0.1448
Number of observations			4,738

Notes: Robust standard errors in parenthesis; non-adoption is the reference category. ***, ** and * represent significance levels at 1 %, 5 %, and 10 % respectively.

References

Abdulai, A.N., 2016. Impact of conservation agriculture technology on household welfare in Zambia. Agricultural Economics. 47 (6), 729–741.

Ahmed, M.H., 2022. Impact of improved seed and inorganic fertilizer on maize yield and welfare: evidence from eastern Ethiopia. Journal of Agriculture and Food Research 7. https://doi.org/10.1016/j.jafr.2021.100266.

Amankwah, A., Quagrainie, K.K., 2019. Aquaculture feed technology adoption and smallholder household welfare in Ghana. Journal of the World Aquaculture Society.

Amankwah, A., Quagrainie, K.K., Preckel, P.V., 2018. Impact of aquaculture feed technology on fish income and poverty in Kenya. Aquaculture Economics & Management. 22 (4), 410–430. https://doi.org/10.1080/13657305.2017.1413689.

Atta-Ankomah, R., Osei, R.D., 2021. Structural change and welfare: a micro panel data evidence from Ghana. The Journal of Development Studies 57 (11), 1927–1944.

Becerril, J., Abdulai, A., 2010. The impact of improved maize varieties on poverty in Mexico: a propensity score-matching approach. World Development 38 (7), 1024–1035.

Bellon, M.R., Risopoulos, J., 2001. Small-scale farmers expand the benefits of improved maize germplasm. a case study from Chiapas. Mexico. *World Development* 29, 799–811.

Bellon, M.R., Adato, M., Becerril, J., Mindek, D., 2006. Poor farmers' perceived benefits from different types of maize germplasm: the case of creolization in lowland tropical Mexico. World Development 34, 113–129.

Bourguignon, F., Fournier, M., Gurgand, M., 2007. Selection bias corrections based on the multinomial logit model: Monte-Carlo comparisons. Journal of Economic Surveys 21, 174–205.

Collier, P., Dercon, S., 2014. African agriculture in 50 Years: smallholders in a rapidly changing world? World Development 63, 92–101.

Deb, P., Trivedi, P.K., 2006. Maximum simulated likelihood estimation of a negative binomial regression model with multinomial endogenous treatment. Stata Journal 6, 246–255.

Di Falco, S., 2014. Adaptation to climate change in sub-Saharan african agriculture: assessing the evidence and rethinking the driver. European Review of Agricultural Economics. 41 (3), 405–430.

Diao, X., Hazell, P., Thurlow, J., 2010. The role of agriculture in african development. W*Orld Development*. 38, 1375–1383.

Dillon, A., McGee, K., Oseni, G., 2015. Agricultural production, dietary diversity and climate variability. The Journal of Development Studies 51 (8), 976–995. https://doi.org/10.1080/00220388.2015.1018902.

FAO, IFAD, UNICEF, WFP and WHO, 2021. The state of food security and nutrition in the World: transforming food systems for food security, improved nutrition and affordable healthy diets for all. https://data.unicef.org/resources/sofi-2021/.

Foster, J., Greer, J., Thorbecke, E., 1984. A class of decomposable poverty measures. Econometrica 52 (3), 761–766.

Gertler, P.J., Martinez, S., Premand, P., Rawlings, L.B., Vermeersch, C.M.J., 2011. Impact evaluation in practice. The World Bank, Washington D.C.

Giller, K.E., 2020. The food security conundrum of sub-Saharan Africa. Global Food Security 26, 100431.

Gitonga, Z.M., De Groote, H., Kassie, M., Tefera, T., 2013. Impact of metal silos on households' maize storage, storage losses and food security: an application of a propensity score matching. Food Policy 43, 44–55.

Government of Zimbabwe, 2018. National Agriculture Policy Framework (2018–2030). Harare, Zimbabwe.

Guo, S., Fraser, M.W., 2010. Propensity score analysis: statistical methods and applications. Sage Publications, UK.

Ifad, 2011. Rural poverty report 2011. International Fund for Agricultural Development, Rome, Italy, p. 2011.

Jaleta, M., Kassie, M., Tesfaye, K., Teklewold, T., Jena, P.R., Marenya, P., Erenstein, O., 2016. Resource saving and productivity enhancing impacts of crop management innovation packages in Ethiopia. Agricultural Economics 47 (5), 513–522.

Jolliffe, I.T., Cadima, J., 2016. Principal component analysis: a review and recent developments. Philosophical Transactions of the Royal Society A 374, 20150202. https://doi.org/10.1098/rsta.2015.0202.

Kassie, M., Shiferaw, B., Muricho, G., 2011. Agricultural technology, crop income, and poverty alleviation in Uganda. World Development 39 (10), 1784–1795.

Kassie, M., Teklewold, H., Marenya, P., Jaleta, M., Erenstein, O., 2015. Production risks and food security under alternative technology choices in Malawi: application of a multinomial endogenous switching regression. Journal of Agricultural Economics 66 (3), 640–659.

Khonje, M.G., Manda, J., Mkandawire, P., Tufa, A.H., Alene, A.D., 2018. Adoption and welfare impacts of multiple agricultural technologies: evidence from eastern Zambia. Agricultural Economics 49, 599–609.

Mazwi, F., Tekwa, N., Chambati, W., Mudimu, G.T., 2018. Locating the position of peasants under the "new dispensation": a focus on land tenure issues. Sam Moyo African Institute for Agrarian Studies, Harare, Zimbabwe.

McFadden, D., 1973. Conditional logit analysis of qualitative choice behavior. In: Zarembka, P. (Ed.), Frontiers in Econometrics. Academic Press, New York.

Mendola, M., 2007. Agricultural technology adoption and poverty reduction: a propensity score matching analysis for rural Bangladesh. Food Policy 32 (3), 372–393.

Mundlak, Y., 1978. On the pooling of time series and cross section data. Econometrica 64, 69–85.

Murendo, C., Chirongwe, C., Sisito, G., 2022. Food expenditure shares and income elasticities in Zimbabwe: accounting for gender and poverty differences. Cogent Economics & Finance 10 (1), 2101241. https://doi.org/10.1080/23322039.2022.2101241.

National Statistics Agency (ZimStat), 2017. Zimbabwe poverty report 2017. Harare, Zimbabwe.

National Statistics Agency (ZimStat), 2019. Zimbabwe smallholder agricultural productivity survey 2017. Harare, Zimbabwe.

Ndlovu, P.V., Mazvimavi, K., An, H., Murendo, C., 2014. Productivity and efficiency analysis of maize under conservation agriculture in Zimbabwe. Agricultural Systems 124, 21–31.

OECD/FAO, 2016. OECD-FAO agricultural outlook 2016–2025. OECD Publishing, Paris. https://doi.org/10.1787/agr_outlook-2016-en.

Pindiriri, C., 2018. Breaking the Traditional Trap: Assessing Drivers of Modern Technology Adoption by Smallholder Farmers in Hurungwe District, Zimbabwe. in "building a Resilient and Sustainable Agriculture in Sub-Saharan Africa". Palgrave Macmillan. A., Verdier-Chouchane, A., Boly, A.

Rubin, D., Imbens, G., 2015. Causal inference for statistics, social, and biomedical sciences: an introduction. Cambridge University Press, US.

Slavchevska, V., 2015. Agricultural production and the nutritional status of family members in Tanzania. The Journal of Development Studies 51 (8), 1016–1033. https://doi.org/10.1080/00220388.2015.1018906.

Suri, T., Udry, C., 2022. Agricultural technology in Africa. Journal of Economic Perspectives 36 (1), 33–56.

Teklewold, H., Kassie, M., Shiferaw, B., Köhlin, G., 2013. Cropping system diversification, conservation tillage and modern seed adoption in Ethiopia: impacts on household income, agrochemical use and demand for labor. Ecological Economics 93, 85–93.

Tesfaye, W., Blalock, G., Tirivayi, N., 2020. Climate-smart innovations and rural poverty in Ethiopia: exploring impacts and pathways. American Journal of Agricultural Economics 103 (3), 878–899. https://doi.org/10.1111/ajae.12161.

USDA, 2021. Grain and feed annual, Zimbabwe. Global Agricultural Information Network (GAIN), Pretoria. RH2021-0002.

Wongnaa, C.A., Awuyo-Vitor, D., Bakang, J.E.A., 2018. Factors affecting adoption of maize production technologies: a study in Ghana. The Journal of Agricultural Studies 13, 81–99.

World Bank, 2008. World development report 2008: agriculture for development. The World Bank, Washington D. C.

World Bank, 2019. Zimbabwe public expenditure review: with a focus on agriculture. World Bank, Washington DC.

Wu, H., Ding, S., Pandey, S., Tao, D., 2010. Assessing the impact of agricultural technology adoption on farmers' well-being using propensity-score matching analysis in rural China. Asian Economic Journal 2, 141–160.

Zikhali, P., 2008. Fasttrack land reform, tenure security and investments in Zimbabwe. Environment for Development Discussion Paper Series EfD DP 08–23.