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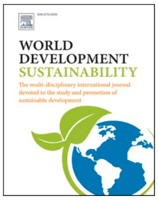

Regional efficiency and total factor productivity change for small and medium sorghum producers in Zambia: A slacks-based measure and Malmquist index approach

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ABSTRACT

Zambia's efforts to promote countrywide production of sorghum is backed by a number of apropos factors. It is not only an adaptive response to the climate change challenge, but also a dietary diversity improvement measure, to achieve food and nutrition security. Further, improved sorghum production will supply emerging agro-industries, especially specialty foods, beverages and stock feed manufacturing in the country. However, regional sorghum production efficiencies in Zambia are not well known. This paper attempts to evaluate regional sorghum production technical efficiencies (TE), as well as Total Factor Productivity (TFP) change from 2011 to 2022. To study these aspects, we apply non-parametric Data Envelopment Analysis (DEA) techniques such as the Slacks-Based Measure (SBM), and the Malmquist Productivity Index (MPI), followed by bootstrap OLS regression respectively. Cross-sectional estimates from the SBM model for the 2022 cropping season indicate that average TE for small and medium sorghum farmers in Zambia was 85 percent. Sorghum production could be expanded by 411.90 t by improving TE in five of ten provinces in Zambia. The MPI shows that TFP for sorghum production in Zambia declined by 21 percent, mainly due to deteriorating sorghum production technology. Populations, rurality, agro-ecological zone IIB are the factors associated with EC and TFP decline.

1. Introduction

As climate change continues to constrain food and nutritional security in drought-prone semi-arid regions of Africa, governments are trying to introduce various climate-smart and drought-tolerant agricultural measures and practices to counter the adverse effects [1,2]. Sorghum (*Sorghum bicolor* L. Moench) is one of the crops that are well adapted to drought conditions and also provides nutritional advantage [3,4]. In the past, production of sorghum and other minor crops was almost neglected as it was not supported by governments through the course of economic development [5]. As a result, the maize (*Zea mays*) monoculture exacerbated the damage caused by drought in many sub-Saharan (SSA) countries including southern Africa. Among other measures, Zambia is encouraging its rain-dependent small and medium scale farmers to produce sorghum. It is believed that this will strengthen farmers' resilience against drought-induced food insecurity and will improve dietary and nutritional sources [6,7]. During the 1991/92, 2015/16 and 2019/20 cropping seasons, nearly 9 million people cumulatively faced hunger and starvation due to severe drought and the subsequent maize failure in Zambia [8,9].[1] Further, the Africa Region Health Report (ARHR) of 2006 points out the rising lifestyle health conditions and chronic diseases such as obesity, hypertension, cancer and diabetes in Africa [10]. Meanwhile, wholesome diversification of nutrient sources is thought to improve overall health [11–14]. Research shows that sorghum is a rich source of critical micronutrients such as iron, vitamin B6, anti-oxidants, cancer inhibitors and is gluten free [15,16]. Furthermore, the recent emergence of some commercial entities in Zambia, utilizing sorghum for production of diverse beverages, livestock and fish feed concentrates [17] calls for expanded sorghum output volumes. Additional demand for sorghum comes from some neighboring countries within the Southern African Development Community (SADC) [18]. These aspects highlight the potential benefits from the sorghum subsector in Zambia, in terms of its contribution to food security, health, and economic growth.

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[1] Intentional Infliction of Emotional Distress (IIED) and Humanist Institute for Cooperation with Developing Countries (HIVOS) 2017 and 2019 Discussion Papers highlight that Zambia's dietary diversity index is among the lowest, compared to other sub-Saharan countries.

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However, the Food and Agriculture Organization Statistics (FAOSTAT), show a sustained decline in sorghum production in Zambia, since the 1970s.[2] It is argued that sorghum is one of the traditional cereal crops which lost much of its appeal and popularity among smallholder farmers in Zambia, due to its lower yields, compared to maize. Although it is considered as a low-input crop, sorghum's susceptibility to bird attacks especially for low-tannin varieties demands extra bird-scaring labor [5,19]. Further, land fragmentation due to population growth has forced small and medium scale farmers to prioritize production of the staple maize crop [1]. Moreover, low domestic demand for sorghum due to the population's static food tastes, and the lack of robust commercial use for the so-called minor crops are additional factors which stifled sorghum production in Zambia [20,21]. Hence, despite the intensified propagation of crop diversification messages in Zambia, physical incentives for production of minor crops have been negligible. The Farmer Input Support Program (FISP) and the Food Reserve Agency (FRA) are primarily focused on production and marketing of the staple maize crop respectively.[3] Thus, successive small and medium scale farmers in Zambia considered sorghum production as a supplementary, rather than a complementary undertaking to the maize enterprise. Nevertheless, sorghum remained an important commodity for human consumption, fodder, and malting in the brewery cottage industry within Zambia's rural communities. In 2020, the Zambian government extended the direct input supply (DIS) subsidy under FISP to small and medium scale sorghum farmers across the country. Previously, such support was limited to the FISP electronic voucher (E-voucher) program, implemented in the Luangwa and Zambezi valley districts of Lusaka and Southern provinces.

This paper posits that sorghum productivity challenges can partially be addressed by improving regional production efficiencies to achieve better harvests for the current and future needs [22,23]. Therefore, the purpose of this research is to seek policy options for raising sorghum output in Zambia. We ask three research questions as follows;

1) What are the current technical efficiencies (TE) for regional sorghum production in Zambia?
2) Where there any regional efficiency changes (EC), technological changes (TC), and total factor productivity (TFP) changes during the 2011 to 2022 period?
3) What factors were associated with EC, TC and TFP changes during the same

period?

To answer these questions, we consider small and medium scale farmer focused research as encouraged in Ceres2030: sustainable solutions to end hunger (SSEH) [24], which found a strong association between rural poverty and food insecurity among smallholders, despite the fact that more than 83 percent of world farmlands belonged to them. For our backdrop, the 2022 Crop Forecast Survey (CFS) data by Zambia Statistics Agency (ZamStats) show that small and medium scale sorghum farmers in Zambia were responsible for 91.4 percent of the 18,372 t (MT) of national output. Our results show that in 2022 there were sorghum output slacks in 5 of 10 provinces in Zambia, and that between 2011 and 2022, technological deterioration was the main driver of TFP decline for sorghum producers in Zambia. This study contributes new knowledge for policy makers, sorghum producers, and researchers in Zambia and other SSA countries.

The rest of this paper is structured as follows; section two provides a review of literature, while section three shows the framework of our analytical methods and study area description. Section four presents data sources and data characteristics. Results and discussion of the empirical findings are provided in section five. The conclusion and policy recommendations are presented in section six.

2. Review of literature

In the first part, we take an anthological review of literature on TE for sorghum production from the East, Central, West, and Southern African regional perspectives. In the second part, we narrow down to research done in Zambia on the same subject.

2.1. Sorghum production efficiency in sub-Sahara Africa

Research conducted on TE for smallholder sorghum farmers in Adamawa state in Nigeria, Machakos and Makindu districts of lower Eastern Kenya, Rahad scheme in Sudan and Konso district in Ethiopia [25–28], found different levels of TE, at 73, 41, 78, and 69 percent respectively. These suboptimal TE figures for sorghum production in different parts of the continent indicate that room for TE improvement exists. However, no evidence of technical inefficiency (TI) was found for sorghum producers in the central zone of Tigray in Ethiopia [29]. Variations were attributed to stochastic factors beyond the farmers' control. This perhaps indicates that with right conditions, maximum TE is achievable by smallholder sorghum farmers. Researchers used different methodologies such as Tobit regression and stochastic frontier analysis (SFA), to find that farm level and technological factors, including regional characteristics were important determinants of TE for sorghum production. Regarding farmer characteristics in East, Central, and West African regions, formal education, farming experience, membership in farmer associations, extension services, and off-farm income contributed positively to TE. Surprisingly, household size which was expected to enhance family labor had a negative impact on TE for sorghum production [29]. This was attributed to labor misallocation. The most important technological factors included the use of improved seed varieties (ISVs) for high yields, disease and drought resistance. Others were fertilizers, herbicides and pesticides, animal draft power (ADP), and irrigation facilities. Regional factors were sorghum markets and soil fertility statuses. In the SADC region, sorghum's potential to contribute to food security and livelihood support has long been recognized [30–33]. But the low production scale and insignificant policy support reinforced sorghum's marginalization from the research agenda [34]. However, in recent years frequent drought episodes in the region have provoked renewed interest in the commodity. But sorghum studies in SADC so far have not adequately addressed sorghum production efficiency [35].

2.2. Sorghum production efficiency in Zambia

There is only one known piece of literature on estimation of sorghum production efficiency in Zambia. Chimai et al. [36] employed the Charnes, Cooper and Rhodes (CCR) and Banker, Charnes and Cooper (BCC) models in Data Envelopment Analysis (DEA), to estimate cross-sectional efficiency scores for sorghum production using nationally representative panel data from 1999 to 2008. They found a lower average TE score of 34 percent, compared to other countries in SSA. Then they applied Ordinary Least Squares (OLS) regression to evaluate determinants of TE for smallholder sorghum farmers in Zambia. However, their findings confirmed the importance of technological innovation for increasing sorghum output through fertilizer applications and use of ADP for tillage. Like the findings in Ethiopia [29], larger household size and a higher number of dependents were found to affect TE negatively. They attributed this to decreased marginal productivity of labor [36]. The findings by Chimai et al. indicated that farmers located in the arid agro-ecological region I were technically more efficient sorghum producers than otherwise.

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[2] FAO crop production statistics available at: https://www.fao.org/faostat/en/#data/QCL/visualize. (accessed on 16 August 2021).

[3] https://www.iied.org/sites/default/files/pdfs/migrate/G04422.pdf. (accessed on 13 March 2023).

However, other research articles on sorghum production in Zambia relate to its agronomy, breeding, adoption of ISVs, value chain development, and sorghum markets. These articles provide valuable insight into the main focus of research activities in the sorghum subsector in Zambia. For instance, the technological interventions in Zambia's sorghum production illuminate that the adoption rate of ISVs is only 33.5 percent among small-scale farmers [37]. While the Sorghum and Millets Improvement Program (SMIP) at Zambia Agricultural Research Institute (ZARI) had released 16 ISVs in Zambia since the early 1980s [38], the Integrated Seed Sector Development (ISSD) report on climate-resilient seed systems, access and benefit-sharing of 2017 records that 23 sorghum ISVs were made available in Zambia by different players from the 1960s to 2015. The Zambia Seed Company (Zamseed) being responsible for 13 of them. Nonetheless, Hamukwala et al. [39]. found that poor farmer access to the ISVs had constrained yield levels for both sorghum and millet to about 0.5 tons per hectare for over 20 years [40]. They found that producers relied on farm recycled seed during the intervening period. The development of a range of ISVs, farmer-market linkages and more research were recommended. However, the probable attachment of sentimental value to local seed varieties as vintage or heritage germplasm by some farmers could also be a disincentive for ISV adoption [41]. In keeping with recommendations by Hamukwala et al., Mbulwe et al. [42] hypothesized that a participatory sorghum breeding and variety selection approach would deliver better results in terms of adoption rates for the available ISVs. Those researchers considered 12 sorghum varieties for a study conducted in Milenge district of Luapula province in Zambia. Results indicated that adoption rates for a number of underutilized high yielding open pollinated varieties (OPVs) which included red and white sorghum (ZSV-36R, ZSV 15, ZSV16, Sima, and Kuyuma respectively) improved during this study. But while ISVs were recommended, their availability and access by smallholder farmers in Zambia remained problematic. Until 2020, sorghum seed was not a regular part of the FISP-DIS package,[4] except under the limited but more flexible FISP E-voucher system, where farmers exercised choice of inputs.

The absence of robust domestic and commercial consumer markets for the 'minor crops' could be a major hindrance to widespread smallholder adoption of improved sorghum in Zambia. As such, the impact of Structural Adjustment Program (SAP) policies in the 1990s was found to have left a huge gap in the market structure for agricultural commodities in Zambia [43]. Hence, deliberate efforts to develop both input and output markets were recommended. In that sense, other researchers [44] analyzed Critical Success Factors (CSF) of the final markets for sorghum-based stock feed manufacturing in Lusitu area of Chirundu district in southern Zambia. They found that on one hand, public-private partnership (PPP) efforts to strengthen value addition for sorghum affected prices for domestic consumers, while commercial customers cared for price, reliability of deliveries and availability of financial capital to remain competitive in the market. On the other hand, suppliers (sorghum farmers) placed value on quality and quantity requirements of the buyers.

This review of literature reveals that in East, Central and West African states, researchers have extensively examined sorghum production efficiency and its determinants by parametric methods such as Tobit, SFA and other methods applied to farm level data. But so far, little research has been conducted in Zambia and the SADC region in this regard. We also find that there are knowledge gaps in terms of regional efficiencies and TFP changes for sorghum production in Zambia and other SSA states. This study expands on the scope covered by Chimai et al. [36].

3. Materials and methods

Agricultural production systems are multi-input takers. However, not all producers achieve output quantities that are proportionate with the scale of input usage. Over use of inputs for a given level of output (input oriented) or shortfalls in output for a given level of inputs (output oriented), subject to the production technology, is undesirable production inefficiency. There are several parametric and non-parametric methods of measuring TE of production units [45]. However, we do not go further due to lack of space.

3.1. Data envelopment analysis

This paper applies the non-parametric econometric models in DEA, followed by OLS regression for evaluation of factors associated with TFP changes. DEA is based on linear programming methods to estimate efficiency of production entities. Introduced in 1982 [46], this units–invariant approach is our best method for peer benchmarking of inefficient decision-making units (DMUs), against the best performing ones on the frontier surface. DMUs are those production entities which decide input levels or those which set the output targets of production processes. Unlike parametric SFA, DEA does not require specification of the functional form [47]. Further, DEA models have the advantage of being applicable on small samples, as is the case in this study [48]. DEA techniques have been applied in many agricultural production efficiency studies over time [49–52].

3.1.1. Cross-sectional efficiency measure

To elicit a comprehensive understanding of cross-sectional efficiency measurement in DEA, we examine three related output-oriented models in form of CCR, BCC and the Slacks Based Measure (SBM) as follows;

3.1.1.1. The CCR model. The CCR model [46]is the basic DEA methodology for measuring efficiency of DMUs, by maximizing the feasible output from a given set of inputs (output oriented). Assuming constant returns to scale (CRS), CCR-efficiency implies scale efficiency. Hence, CCR-efficiency is also known as global TE. However, with some inputs limited, the law of diminishing returns does not guarantee scale efficiency. The linearized formula for the CCR model is given as follows;

$$\begin{aligned}
&(\text{CCR})\underset{u,v}{max}\theta = uy_{ro} \\
&\textbf{Subjectto}: \quad \nu_i x_i = 1 \\
&\qquad \nu_i X_{ij} \geq u_r Y_{rj} \qquad (j = 1, \dots, n) \\
&\qquad u_r \geq 0,\ \nu_i \ \geq 0.
\end{aligned} \tag{1}$$

where x_i and y_r are vectors for the input and output variables respectively. v_i and u_r are vectors of the weights for input and output observations, where $0 \leq \theta \leq 1$.

3.1.1.2. The BCC model. The BCC model [53] estimates pure technical efficiency (PTE) of DMUs. This distance function model seeks to maximize the output-input ratio, assuming variable returns to scale (VRS) due to diminishing returns. The linearized BCC model is given by the following;

$$\begin{aligned}
&(\text{BCC})\ \underset{u,v}{max}\theta_B = uy_{ro} - u_{o,} \\
&\textbf{Subjectto}: \quad vx_o = 1 \\
&\qquad vX \geq uY - \ u_o \\
&\qquad \nu_i \geq \varepsilon,\ u_r \geq \varepsilon, \quad u_o\ \textbf{freeinsign}
\end{aligned} \tag{2}$$

where u_o is used to identify the nature of RTS in the model. Again $0 \leq \theta \leq 1$.

Fig. 1 shows that the tighter BCC frontier contains more efficient DMUs than the CCR frontier, because of the VRS assumption.

3.1.1.3. Scale efficiency. The CCR/BCC ratio score gives the scale

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[4] http://www.ennonline.net/nex/5/zambiaagriculturefornutrition. (accessed on 4 April 2022).

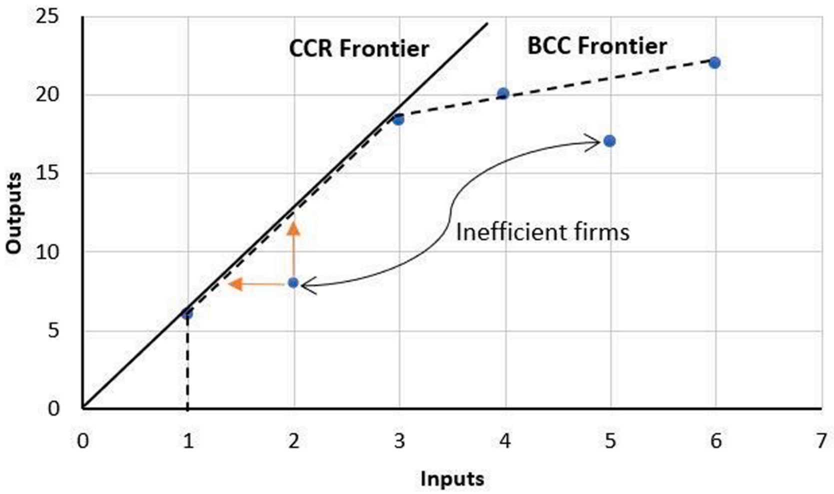

Fig. 1. CCR and BCC Efficiency Measures.

efficiency (SE) aspects that are not captured in the BCC model [54];

$$SE = CCR_\theta / BCC_\theta \tag{3}$$

Similarly, SE score ranges between 0 and 1. A DMU can be efficient in terms of PTE by being BCC-efficient but not CCR-efficient due to scale inefficiency. The SE value is dependent on the difference between CCR and BCC scores. Thus, the closer the BCC score is to the CCR score, the higher the SE.

3.1.1.4. The SBM model. Proportional radial efficiency measures such as CCR and BCC do not take account of the input excesses and output shortfalls in case of non-zero slacks due to technology failures. The Slacks-Based Measure (SBM) introduced by Tone in 2001 [54] is an overall efficiency model. Computation of the non-radial output-oriented SBM model at CRS is as follows;

$$(SBM)\ \min_{\lambda,\, s^-,s^+} \rho = \frac{1-\frac{1}{m}\sum_{i=1}^{m} s_i^- / x_{io}}{1+\frac{1}{s}\sum_{r=1}^{s} s_r^+ / y_{ro}}$$

$$\text{Subject to:} \quad x_o = X\lambda + s^- \tag{4}$$

$$y_o = Y\lambda - s^+$$

$$\lambda \geq 0,\ s^- \geq 0,\ s^+ \geq 0$$

where s^- and s^+ are input and output slacks respectively, X and Y are vectors of input and output variables weighted by λ. The SBM index ρ lies within $0 \leq \rho \leq 1$ range.

3.1.1.5. Mix efficiency. Mix efficiency (ME) is the ratio of SBM and CCR efficiency scores. Fig. 2 illustrates input mix inefficiency measurement, where OPQRSTU are scatterplot observation data points. Assuming only two inputs X_1 and X_2, inefficient DMU labelled U can become efficient by reducing both inputs radially down to the frontier isoquant at U'. But at U' there would be slacks for input X_2 which can be reduced further to T, while achieving the same level of output.

ME is measured by the following equation;

$$ME = SBM_\rho / CCR_\theta \tag{5}$$

From (3) and (5), the relationships can be rearranged to give rise to the following;

$$\begin{aligned} &CCR_\theta = SE\ x\ BCC_\theta \\ &SBM_\rho = ME\ x\ CCR_\theta \ \ \textbf{therefore}, \\ &SBM_\rho = ME\ x\ \ SE\ x\ BCC_\theta \end{aligned} \tag{6}$$

Thus, (6) shows that the SBM model is a universal measure of efficiency which incorporates CCR and BCC efficiency. Hence, we will primarily base our cross-sectional efficiency interpretations on SBM.

3.1.2. Panel efficiency measure

For efficiency change over time, as per our second objective, we use panel data to estimate TFP change by the Malmquist Productivity Index (MPI) [55] for the time period 2011 to 2022. The conventional methodology has been built on earlier ideas on panel efficiency measurement [56]. The methodology continued to be refined over time [57]. The output-oriented distance function (D_o) for period (t) can be represented by $D_o^t(x^t, y^t)$. For the second period ($t + 1$), we have $D_o^{t+1}(x^{t+1}, y^{t+1})$ constructed similarly. According to Färe et al. [57], efficiency change (EC) or catch up between two-time periods is the ratio;

$$EC = \frac{D_o^{t+1}(x^{t+1},\ y^{t+1})}{D_o^t(x^t,\ y^t)} \tag{7}$$

where EC is efficiency change, x^{t+1} and y^{t+1} are input and output quantities under period two technology. Likewise, the denominator represents first period input x^t and output quantity levels y^t under period one technology. Technological change (TC) is found by the geometric mean (GM) of first and second period input and output quantities under period one and two technologies;

$$TC = \left[\left(\frac{D_o^t(x^{t+1},\ y^{t+1})}{D_o^{t+1}(x^{t+1},\ y^{t+1})}\right)\left(\frac{D_o^t(x^t,\ y^t)}{D_o^{t+1}(x^t,\ y^t)}\right)\right]^{\frac{1}{2}} \tag{8}$$

Accordingly, the output-oriented MPI is therefore, a multiplicative function of aggregate indices from (7) and (8), expressed as;

$$M_o\left(x^{t+1},\ y^{t+1}, x^t,\ y^t\right) = \frac{D_o^{t+1}(x^{t+1},\ y^{t+1})}{D_o^t(x^t,\ y^t)} * \left[\left(\frac{D_o^t(x^{t+1},\ y^{t+1})}{D_o^{t+1}(x^{t+1},\ y^{t+1})}\right)\left(\frac{D_o^t(x^t,\ y^t)}{D_o^{t+1}(x^t,\ y^t)}\right)\right]^{\frac{1}{2}} \tag{9}$$

where M_o is the output-oriented index measuring MPI by $EC\ x\ TC$ [57,58]. An MPI value above 1 indicates overall TFP improvement between two time periods. A value of 1 denotes no change in TFP while a value less than 1 indicates a decline in efficiency from t to $t + 1$. The same logic applies for the EC and TC indices.

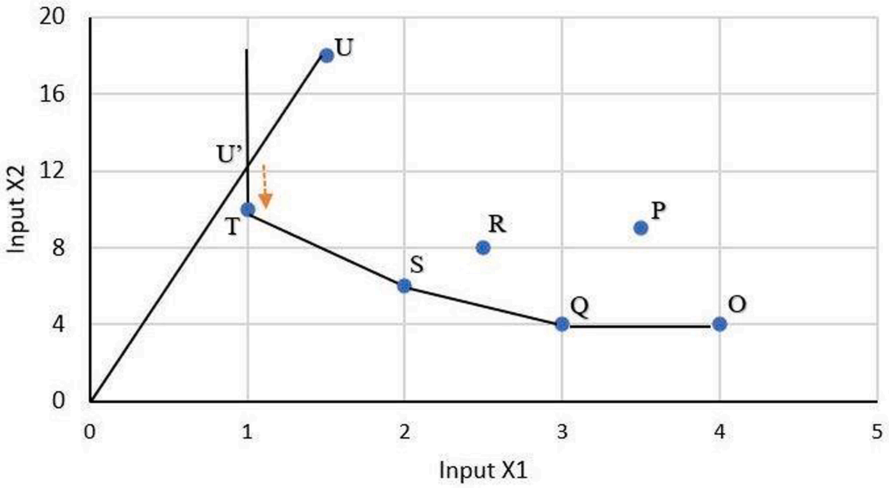

Fig. 2. Mix Efficiency Illustration.

3.1.3. *Factors associated with efficiency change (EC), technological change (TC) and Malmquist productivity index (MPI)*

To answer our third objective, we evaluate regional factors associated with EC, TC, and MPI scores, using panel data. This kind of evaluation uses random effects (RE), Fixed Effects (FE), Generalized Least Squares (GLS) or Feasible Generalized Least Squares (FGLS) models [59–61]. However, the Hausman test for selecting between RE and FE models, and the Breusch-Pagan Lagrange multiplier (BP-LM) for selecting between RE and OLS models did not favor the application of RE and FE models in this case [62]. Further, literature suggests that GLS and FGLS are more suitable for analysis of large or long period panel data samples than otherwise [63–65]. Hence, we primarily consider bootstrap OLS for this analysis. Bootstrapping was conducted to achieve robust estimates of population parameters, by sampling distribution from the original sample of our variously sourced secondary data [66, 67]. The formula is represented as;

$$\ln Y_{it} = \beta_0 + \beta_1 \ln X_{it} + \beta_2 D_{it} + \beta_3 COVID19_t + \varepsilon_{it} \quad i = 1, 2, 3 \ldots n \tag{10}$$

where $\ln Y_{it}$ is the natural log of an outcome variable in province i and time t. The outcome variables include EC, TC, and MPI. $\ln X_{it}$ is a vector of log transformed province i's characteristics such as rainfall and population observed in year t. D_{it} represents a vector of time-variant (e.g., FISP E-voucher) and time-invariant (e.g., rural) dummy variables for province i. $COVID19_t$ is a dummy representing the period after 2020. Lastly, ε_{it} is an error term.

3.2. *Study area description*

Our study area comprises all ten administrative regions which are shown overlaid on Agro Ecological Zones (AEZs) in Fig. 3, as compiled using open source QGIS software. The country lies in the tropical region of Southern Africa between longitudes 22° and 33° east of the Greenwich meridian and between latitudes −8 to −18° south of the Equator [54]. AEZs are classified according to local climatic conditions and soil types.[5] Despite cross-boundary heterogeneity, AEZ I is conventionally taken to include Lusaka and Southern provinces. It receives less annual rainfall (400–800 mm). Similarly, AEZ IIA encompasses Central and Eastern provinces. This region experiences medium amounts of rainfall (600–1000 mm). AEZ IIB covers Western province and it also receives 600–1000 mm of rainfall. Different soil types being the main distinction between AEZ IIA (mixed loams) and AEZ-IIB (Kalahari sands). AEZ-III covers Copperbelt, Luapula, Muchinga, Northern and North-Western provinces.

This is the wettest AEZ in Zambia, with maximum annual rainfall topping 1500 mm. According to Ministry of Agriculture (MoA) and ZamStats' farmer classification, small scale farmers in Zambia grow up to 5 ha of cropland. Medium scale farmers cultivate between 5 and 20 ha. Above 20 ha are large scale commercial farmers [68]. Small scale farmers depend on family and sometimes hired labor for farm operations. Tillage technology is typically hand hoe especially for farmers in AEZ III. Nevertheless, use of ADP by traditional pastoralists in Central, Eastern, Southern and Western provinces is common.

The smallholders' primary objective is to achieve household food security. However, income generation is increasingly becoming the important motive for many. Fig. 4 shows regional sorghum production for the period under review. It shows that Southern province was the highest sorghum producer in Zambia, followed by Muchinga and Western provinces. However, sorghum production in Lusaka, Southern and Western provinces dipped in 2015 and 2019 due to severe drought experienced in those regions.

4. DATA sources and data characteristics

The data used in this study were obtained from various secondary sources

4.1. *Cross-sectional data for regional TE measurement*

For cross-sectional DEA analysis, we use Crop Forecast Survey (CFS) data from ZamStats. The statistics agency in Zambia uses weights to aggregate district level CFS data into regional level data [69,70]. However, the dataset does not include seed quantity, seed variety and commodity price; hence, these variables were not applicable in this study. From the ZamStats CFS dataset we chose three physical input variables, viz; planted crop area (ha), fertilizer (MT) and labor (number of sorghum-producing households). The output variable was sorghum production (MT). Table 1 shows regional input and output quantities in 2011 and in 2022, for small and medium scale sorghum producers in Zambia. The data starts from 2011 when Muchinga province was created, by annexation of some districts from Eastern and Northern provinces.

We use the 2021/2022 sorghum input and output data for our cross-sectional analysis, to depict the most recent regional efficiency levels for the ten provinces as DMUs in the dataset. Three inputs and one output satisfy the rule of thumb for good discriminatory power of the CCR and

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[5] Agroecological zone coverage in Zambia: https://www.fao.org/3/x6611e/x6611e02f.htm (accessed 30 November 2021).

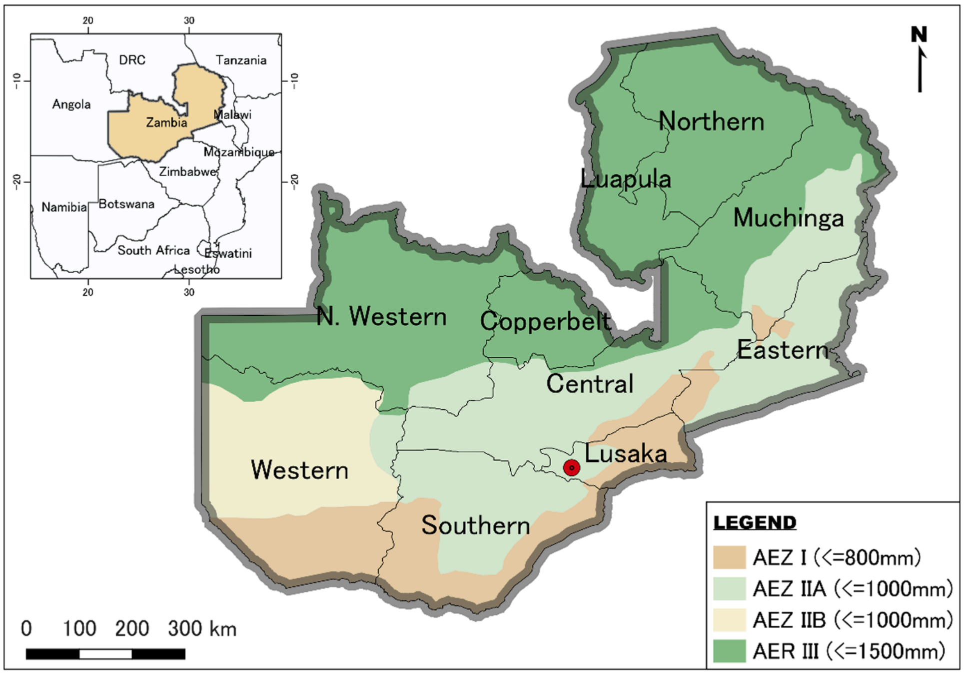

Fig. 3. Regional Administrative Areas and AEZs of Zambia.
Source: Authors' compilation.

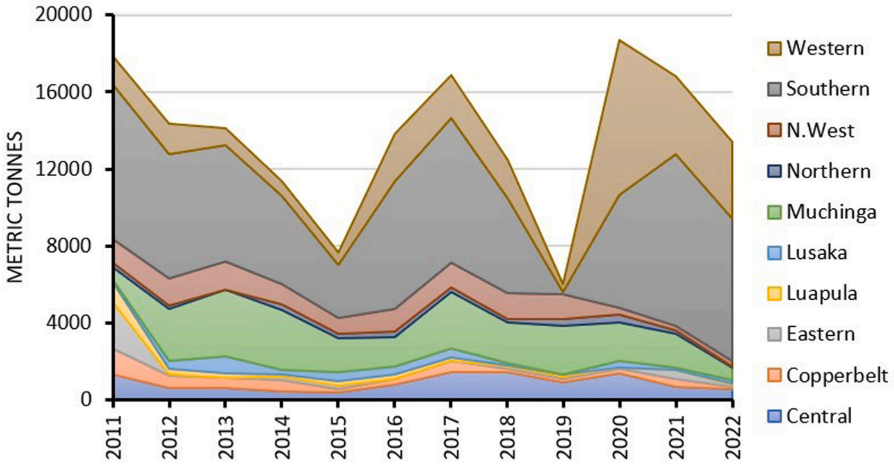

Fig. 4. Small and Medium Scale Sorghum Production in Zambia by Region.
Source: Authors' compilation from ZamStats CFS data

Table 1
Summary statistics for regional sorghum production by small and medium scale farmers in Zambia.

	Planted Area (Ha)		Fertilizer (MT)		Labor (HH)		Production (MT)	
DMU	2011	2022	2011	2022	2011	2022	2011	2022
Zambia	25,868.08	29,166.63	256.00	195.10	48,139	47,834	17,875.46	13,421.85
Central	1671.09	876.14	12.00	0.00	4911	2040	1305.86	555.16
Copperbelt	1552.97	219.39	0.00	17.90	3377	282	1387.53	151.60
Eastern	1889.96	121.05	0.00	0.00	5660	289	2392.19	77.78
Luapula	1188.11	123.44	0.00	8.01	3342	577	1060.94	90.56
Lusaka	178.75	282.23	149.00	8.47	611	888	87.27	156.63
Muchinga	1029.00	715.39	6.00	28.04	3059	2250	689.00	636.03
Northern	182.00	153.06	0.00	2.47	500	623	189.00	100.43
N. western	1667.59	660.87	0.00	11.16	4410	1553	1281.59	283.27
Southern	13,848.93	18,982.61	89.00	44.09	15,503	26,497	8015.56	7375.33
Western	2659.68	7032.45	0.00	74.96	6766	12,835	1466.52	3995.06

Source: Authors' compilation from ZamStats CFS data.

BCC models for ten DMUs [71,72].[6]

4.2. *Panel data for factors associated with efficiency change (EC), technological change (TC) and Malmquist productivity index (MPI) for sorghum production in Zambia*

Table 2 presents descriptive statistics for the variables used in the regression models. Data sources include ZamStats' CFS for sorghum sales volumes, and population and demographic projections (PDP) for population. Literacy data was composited from Training Open Data Portal,[7] parliamentary committee reports on education,[8] and others. Rainfall data was obtained from the World Food Program (WFP) climate services website.[9] The dummies were rural, for all regions in Zambia except Copperbelt and Lusaka which were considered urban, Corona virus (COVID19) pandemic from 2020 to 2022, FISP E-voucher from 2012 to 2022, and FISP-DIS from 2020 to 2022. Export regions include Copperbelt, Muchinga and Western provinces. Others were AEZs I, IIA, IIB and III.

5. Results and discussion

5.1. *Cross-sectional sorghum production efficiency in Zambia*

Table 3 shows cross-sectional efficiency measurement results for the 2021/2022 cropping season, obtained using DEA Solver Pro 11.0. The output-oriented SBM model yielded the efficiency score of 0.854. To close the 15 percent efficiency gap based on Eq. (6), PTE (BCC) needs 7.7 percent improvement. SE could be optimized by 2.5 percentage points and ME increased by 6.7 percent. The SBM-efficient Central and Copperbelt provinces are within central Zambia with good road transport connectivity. There are off taker industries for smallholder sorghum producers, such as Kapiri Breweries, Kankoyo Breweries, Nova Projects Ltd and Zambian Breweries Ltd. Sorghum producers in Eastern, Muchinga and Western regions could easily tap into the Malawi, Tanzania, Democratic Republic of Congo (DRC), Zimbabwe, Botswana, Angola, and South Africa export markets respectively.[10]

Table 2

Descriptive statistics for factors associated with efficiency change (EC), technological change (TC) and Malmquist productivity index (MPI) for small and medium scale sorghum producers in Zambia.

Dependent variables	Obs	Mean	SE	Min	Max
EC	90	1.394	0.083	0.117	11.138
TC	90	1.012	0.029	0.441	1.714
MPI	90	1.234	0.058	0.141	5.429
Independent variables					
Rainfall (mm)	90	958.726	44.923	91.624	1562.735
Population ('000)	90	1646.539	125.454	768.262	3610.977
Literacy levels (%)	90	62.677	0.972	46.900	82.100
No. of companies	90	1.811	0.611	0.000	9.000
Sales volume (MT)	90	376.146	35.445	0.000	4452.216
Dummy variables					
COVID19 (year=1)	90	0.333	0.000	0	1
Rural (yes=1)	90	0.800	0.000	0	1
FISP E-voucher (yes=1)	90	0.178	0.000	0	1
FISP-DIS (yes=1)	90	0.178	0.000	0	1
Export region (yes=1)	90	0.400	0.000	0	1
AEZ I (yes=1)	90	0.200	0.000	0	1
AEZ IIA (yes=1)	90	0.200	0.000	0	1
AEZ IIB (yes=1)	90	0.100	0.000	0	1
AEZ III (yes=1)	90	0.500	0.477	0	1

Bootstrap SEs obtained using Stata 15 software.
Source: Authors' estimation from ZamStats CFS & PDP, WFP and others.

Table 3

Regional Sorghum Production Efficiency Scores for Small and Medium Scale Farmers in Zambia in 2022.

DMU	CCR-O	BCC—O	SBM-O-C	SE	ME
Zambia	0.898	0.923	0.854	0.975	0.933
Central	1.000	1.000	1.000	1.000	1.000
Copperbelt	1.000	1.000	1.000	1.000	1.000
Eastern	1.000	1.000	1.000	1.000	1.000
Luapula	0.825	1.000	0.788	0.825	0.955
Lusaka	0.668	0.680	0.502	0.982	0.752
Muchinga	1.000	1.000	1.000	1.000	1.000
Northern	0.882	0.920	0.866	0.958	0.982
N. Western	0.624	0.625	0.398	0.999	0.638
Southern	0.983	1.000	0.982	0.983	1.000
Western	1.000	1.000	1.000	1.000	1.000

Note: Index of 1 = efficient, less than 1 = inefficient. *O*=output oriented, C=constant returns to scale.
Source: Authors' estimation from ZamStats CFS data.

Although Lusaka and Southern provinces hosted a good number of commercial sorghum consumer companies such as Shais Foods, Omega Foods, Dairy Gold Ltd, Tiger Animal Feeds, Aller Aqua Zambia, Transcontinental fish feed, Kalomo and Kazungula cooperatives respectively, the SBM score shows that there still existed room for improvements in sorghum production by eliminating mix and scale inefficiencies for Lusaka, and scale inefficiency for Southern province. North-Western province was the least efficient sorghum producer due to poor sorghum markets, followed by Lusaka, where producers could easily switch land-use and income sources. Rural Luapula and Northern provinces lacked proper sorghum marketing channels. Table 4 shows the SBM projections for sorghum output, assuming output slacks were removed, and given the input levels. About 13,833.75 MT of sorghum production were possible under current production technology. We find that the slacks, i.e., output shortfalls in Luapula, Lusaka, Northern, North-

Table 4

Projected Regional Expansion of Sorghum Output by Small and Medium Scale Farmers in Zambia.

DMU	Output (MT)	Projected (MT)	% Change	Slack (MT)	Slack (MT/ha)
Zambia	13,421.85	13,833.75	3.07	411.90	0.014
Central	555.16	555.16	0.00	0.00	0.000
Copperbelt	151.60	151.60	0.00	0.00	0.000
Eastern	77.78	77.78	0.00	0.00	0.000
Luapula	90.57	109.74	21.18	19.18	0.155
Lusaka	156.63	234.64	49.81	78.01	0.276
Muchinga	636.03	636.03	0.00	0.00	0.000
Northern	100.43	113.88	13.39	13.45	0.088
N.Western	283.27	453.73	60.18	170.46	0.258
Southern	7375.33	7506.13	1.77	130.80	0.007
Western	3995.06	3995.06	0.00	0.00	0.000

Model = SBM-O-C.
Source: Authors' estimation from ZamStats CFS data.

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[6] Golany and Roll [67] stipulate that the minimum number of DMUs should be twice the product of inputs and outputs (2MN) while Boussofiane, Dyson and Thanassoulis [68] recommend twice the sum of the number of inputs and outputs (2(M + N)).

[7] Literacy data obtained from https://training.opendataforafrica.org/gsqyskg/literacy-rates?lang=en (accessed 20 April 2023).

[8] https://www.parliament.gov.zm/sites/default/files/documents/committee_reports/SECOND%20REPORT%20FOR%20%20EDUCATION.pdf (accessed 20 April 2023).

[9] Rainfall data obtained from https://dataviz.vam.wfp.org/climate-explorer (accessed 23 April 2023).

[10] Sorghum export markets: https://oec.world/en/profile/bilateral-product/sorghum/reporter/zmb (accessed 23 January 2024).

Western and Southern provinces totalled 411.90 MT. This represents 3.07 percent of the 2022 production volume.

But with improved PTE, ME and SE, the national sorghum output could be expanded in five provinces by average 0.014 MT/ha, with the exception of Central, Copperbelt, Eastern, Muchinga and Western provinces which were already at the frontier. Lusaka province had the most potential while Southern province had the least.

5.2. Efficiency change, technological change and malmquist productivity index

Regional EC, TC and MPI performances with base year 2011, are reported in Table 5. We show the Geometric Mean (GM) and Weighted Arithmetic Mean (WAM). WAM is estimated from average regional proportions from total planted area for sorghum in Zambia. For national performance, we rely on WAM figures for the overall period.

5.2.1. Efficiency Change(EC)

Table 5 shows that EC, i.e. regional catch-up with best performing ones (by output expansion), given the production technologies between 2011 and 2022 was 1.27. This implies that EC had improved by 27 percent over the same period. By region, EC improvements occurred in Central, Copperbelt, Luapula, Lusaka, Muchinga and Western provinces during the same period. Given farmers' input limitations, the EC rebound from 2017 to 2021 is indicative of the small and medium scale farmers' efforts to maximize output in that short period owing to improved sorghum demand.

5.2.2. Technological Change(TC)

Table 5 shows that between 2011 and 2022, TC, i.e. frontier shift was 65 percent. This suggests that during that period TC deteriorated by 35 percent. There was overall tillage technology and ISV supply stagnation in Zambia. By region, TC declined in all, although it was slightly better in Lusaka and Southern provinces which had a longer history of supported sorghum production through FISP E-voucher, in Luangwa, Chirundu, Siavonga, and Sinazongwe districts respectively. This outcome is similar to farm level studies in SSA.

5.2.3. Malmquist productivity Index(MPI)

Table 5 shows that MPI, i.e. the product of EC and TC, by which we measure TFP for the entire period was 79 percent. This implies that by 2022, there was a 21 percent TFP deterioration. Only Copperbelt, Lusaka, Muchinga and Western provinces showed TFP improvements during the period under review, due to stronger EC inspired by vigorous local and export markets in those regions respectively. Fig. 5 depicts MPI deterioration as EC and TC fluctuated around a general downward trend from 2012 onwards.

From 2018, EC and TC decoupled as EC rose. This happened as some administrative regions shown in Table 5 caught up in terms of sorghum production output, spurred by recent industrial demand. However, TC always deteriorated, pulling the MPI down. This outcome is corroborated by Baion et al. [73]; Onoja [74], and Myeki et al. [75].

5.3. Factors associated with efficiency change (TC), technological change (TC) and Malmquist productivity index (MPI) for small and medium scale sorghum production in Zambia

Table 6 shows bootstrap OLS results for factors associated with EC, TC and MPI for small and medium scale sorghum production in Zambia. The regression model construction was based on pooled cross-section time series estimation method.

5.3.1. Factors associated with efficiency Change(EC)

Results indicate that significant positive EC was associated with higher literacy levels because literate farmers possessed extra knowledge and skills which they could apply for crop management and

Table 5
Efficiency Change(EC), technological Change(TC) and Malmquist productivity Index(MPI) for small and medium scale sorghum production in Zambia.

																									Overall period	
	2011–2012			**2011–2013**			**2011–2014**			**2011–2016**			**2011–2017**			**2011–2018**			**2011–2020**			**2011–2021**			**2011–2022**		
Region	EC	TC	MPI	EC	TC	MPI	EC	TC	MPI	EC	TC	MPI	EC	TC	MPI	EC	TC	MPI	EC	TC	MPI	EC	TC	MPI	EC	TC	MPI
Central	1.42	0.83	1.17	1.35	0.93	1.25	0.95	1.00	0.94	1.02	0.83	0.85	0.93	1.02	0.95	1.90	0.71	1.34	1.99	0.76	1.52	1.10	0.55	0.60	1.61	0.59	0.96
C/belt	0.76	0.91	0.70	0.86	0.96	0.83	1.64	0.99	1.62	1.27	0.77	0.98	0.85	1.08	0.92	0.68	0.77	0.52	0.57	1.03	0.59	1.39	0.58	0.81	1.77	0.63	1.13
Eastern	0.45	0.86	0.39	0.23	1.03	0.23	0.61	1.12	0.68	0.24	0.71	0.17	0.82	0.95	0.78	0.41	0.81	0.33	0.05	1.19	0.06	0.51	0.60	0.30	0.83	0.62	0.52
Luapula	1.38	0.75	1.04	1.39	0.93	1.29	0.70	1.06	0.74	1.25	0.66	0.82	0.73	1.00	0.74	1.17	0.75	0.87	0.15	1.19	0.18	1.72	0.56	0.96	1.10	0.62	0.68
Lusaka	1.80	0.80	1.44	3.15	0.93	2.94	1.23	1.03	1.27	3.76	0.82	3.09	3.54	0.88	3.11	1.16	0.77	0.89	5.32	0.88	4.70	1.15	0.73	0.83	1.73	0.68	1.18
Muchinga	1.96	0.78	1.53	2.04	0.89	1.81	2.55	0.87	2.22	2.15	0.63	1.36	1.41	1.01	1.43	2.13	0.69	1.47	1.78	0.70	1.25	3.84	0.38	1.47	2.43	0.54	1.32
Northern	0.87	0.78	0.68	0.53	0.93	0.50	0.54	1.00	0.54	0.50	0.68	0.34	0.73	1.02	0.75	0.95	0.75	0.72	1.01	0.85	0.86	1.12	0.41	0.46	0.99	0.57	0.56
N.West.	1.31	0.86	1.12	1.40	0.94	1.32	1.00	1.02	1.02	1.91	0.62	1.19	0.96	1.08	1.03	1.21	0.80	0.96	0.38	1.04	0.40	0.89	0.58	0.52	0.91	0.62	0.56
Southern	1.54	0.97	1.49	0.82	1.10	0.90	0.56	1.25	0.70	0.77	0.88	0.67	0.56	1.02	0.57	0.79	0.82	0.64	0.36	0.95	0.35	0.58	0.56	0.33	0.80	0.68	0.55
Western	1.05	0.76	0.80	0.66	0.94	0.62	0.72	1.03	0.74	0.94	0.72	0.68	0.61	1.06	0.65	0.80	0.80	0.64	2.24	0.82	1.84	2.52	0.37	0.94	2.05	0.62	1.26
GM	1.16	0.83	0.96	0.99	0.96	0.95	0.92	1.03	0.95	1.08	0.73	0.79	0.95	1.01	0.96	1.01	0.76	0.77	0.69	0.93	0.64	1.24	0.52	0.65	1.32	0.62	0.81
WAM	1.38	0.89	1.23	1.05	1.02	1.05	0.91	1.13	0.96	1.12	0.79	0.85	0.78	1.03	0.79	1.00	0.79	0.77	1.02	0.91	0.85	1.32	0.51	0.60	1.27	0.65	0.79

Note: Index of 1 = no change, less than 1 = deterioration and greater than 1= an improvement. Figures denote geometric means with 2011 base year. Index calculations omit the 2015 and 2019 years of severe drought.
Source: Authors' estimation from ZamStats CFS data.

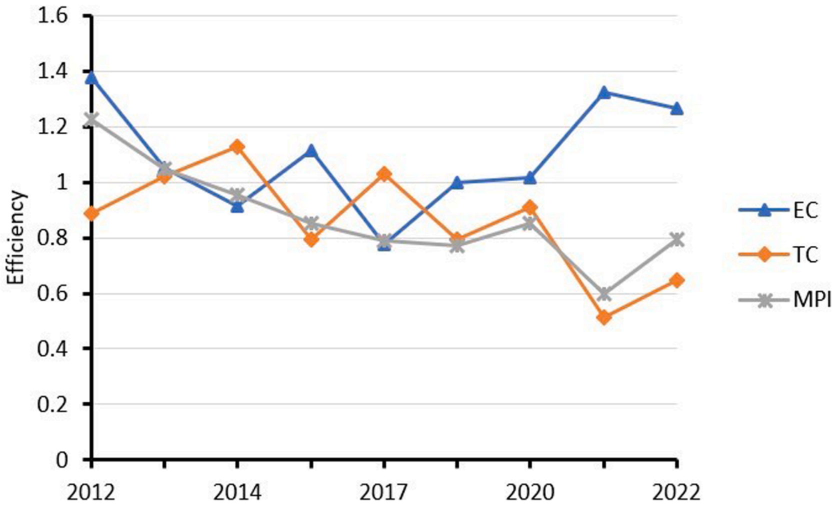

Fig. 5. EC, TC and MPI changes from 2012 to 2022, base year 2011.
Source: Authors' compilation from ZamStats CFS data

Table 6
Factors associated with efficiency Change(EC), Technological Change(TC), and Malmquist Productivity Index(MPI) for small and medium scale sorghum producers in Zambia.

	Bootstrap OLS		
VARIABLES	lnEC	lnTC	lnMPI
Constant	18.677***	2.297	20.975***
	(6.450)	(2.355)	(5.744)
lnRainfall (mm)	−0.032	−0.092	−0.124
	(0.289)	(0.090)	(0.277)
lnPopulation ('000)	−2.003***	0.006	−1.997***
	(0.444)	(0.143)	(0.444)
lnLiteracy level (%)	2.475**	−0.431	2.044**
	(0.989)	(0.361)	(0.889)
lnCompanies (no.)	−0.026	0.016**	−0.010
	(0.021)	(0.007)	(0.019)
lnSales volume (MT)	−0.045	0.014	−0.031
	(0.048)	(0.012)	(0.035)
COVID19 (year=1)	0.424	−0.086	0.338
	(0.335)	(0.084)	(0.284)
Rural (yes=1)	−0.912**	−0.023	−0.935***
	(0.358)	(0.116)	(0.330)
FISP E-voucher (yes=1)	1.171***	0.124	1.295***
	(0.397)	(0.180)	(0.339)
FISP DIS (yes=1)	0.115	−0.382***	−0.266
	(0.364)	(0.088)	(0.316)
Export (yes=1)	0.502**	−0.111*	0.391**
	(0.204)	(0.067)	(0.174)
AEZ I (yes=1)	−0.133	−0.177	−0.310
	(0.526)	(0.189)	(0.469)
AEZ IIA (yes=1)	1.167***	−0.088	1.079***
	(0.333)	(0.099)	(0.315)
AEZ IIB (yes=1)	−0.760**	0.074	−0.686***
	(0.304)	(0.104)	(0.236)
Observations	90	90	90
R-squared	0.385	0.539	0.415

Significance indicated by *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. Bootstrap SEs in parentheses.
Source: Authors' estimation from ZamStats CFS & PDP, WFP and others.

navigation of market conditions to seal contracts. This finding is supported by [76–78]. The dummy for FISP E-voucher subsidy program shows that it contributed to raising average EC, in the sense that farmers who chose to obtain sorghum inputs through the FISP E-voucher program had personal commitment and motivation to grow the crop. This effect may be crop-specific, as it agrees with Siame et al. [79], yet contradicts Mason et al. [80]; Tossou and Bailis [81]. Due to proximity of external markets, sorghum exports significantly induced EC or catch up in sorghum output in border regions of the Copperbelt, Muchinga and Western provinces. Good weather and soil conditions in regions such as Central and Eastern provinces which are covered by AEZ IIA boosted average EC. On the contrary, the significant negative association of EC to population can be explained in terms of producer crowding in given inadequate inputs. This is similar to findings by Mustapha [82]; Wang and Han [83]. Negative EC could be associated with rural regions due to lack of commercial markets. AEZ IIB could be associated with lowering average EC due to poor sandy soils and local markets.

5.3.2. *Factors associated with technological Change(TC)*

TC improvement was positively and significantly associated with the presence of regional commercial companies which could have facilitated contract farming arrangements, whereby available ISVs, and tillage technology were effectively utilized by self-motivated sorghum producers. This is in agreement with Ogundipe et al. [84]. Counterintuitively, TC deterioration was associated with fertilizer and seed distribution, because of the "indiscriminate" nature and crowding in effect under FISP-DIS program, which was not accompanied with tailormade extension messages for unprepared recipients. Ragasa et al. [85].; Tang et al. 2018 [86] found similar results. Another cause was market imperfections resulting into farm level crop switching and disproportionate fertilizer allocations to "more important" crops, as alluded also in Bekata et al. [87] and Okello et al. [88].. Further, TC deterioration could be associated with export-oriented regions such as the Copperbelt, Muchinga and Western provinces which are closer to the DRC, Tanzania and Malawi, Botswana, Zimbabwe, Angola and South Africa, respectively, because of small-scale farmers' limited access to ISVs. This gap can be attributed to strict phytosanitary standards for seed importation, imposed by regulatory bodies such as the Seed Control and Certification Institute (SCCI) and the National Biosafety Authority (NBA) on one hand, and the lack of institutionalized sorghum seed distribution systems, including private agro-suppliers' lack of rural interests on the other. Hence, this gap was filled in by use of farmer managed seed systems in rural/border areas. This is also indicated by Hunga et al. [89], and Linzi and Masinjila [90].

5.3.4. *Factors associated with Malmquist productivity Index(MPI)*

Overall, literacy influenced MPI positively, while E-voucher, sorghum exports, and AEZ IIA contributed to the raising of MPI in the same way as EC. However, the positive influence of these factors was offset by the negative and significant influence of higher populations, rurality, and AEZ IIB on MPI. This means that these variables significantly contributed to lowering of TFP for sorghum production in Zambia. From

Fig. 5 we deduce that after 2018, TC deterioration impacted MPI significantly.

6. Conclusion

Despite many potential benefits from its production, sorghum was still a smallholders' crop in Zambia, which enjoyed niche markets in some regions. Good markets ultimately inspired efficiency improvement in those regions. However, sorghum production technology had been deteriorating in all regions, negatively affecting TFP from 2011 to 2022. Recent countrywide ISV and fertilizer support under FISP only attracted unprepared and inefficient sorghum producers, indicating that more was needed to be done for efficient sorghum production.

Cross-sectional TE evaluation indicates that in 2022, small and medium scale sorghum production improved slightly in Lusaka and Western provinces to surpass the 2011 production levels. However, if the producers were more efficient in 2022, the applied input levels could have resulted in more sorghum output across many regions. But there were output slacks in Luapula, Lusaka, North-western and Southern provinces, which shows the possibility for output expansion in those regions. Thus, the average TE level for sorghum production in 2022 was 85 percent. Closing the 15 percent TE gap could result in a 3 percent national output expansion. This translates into 411.9 MT, which could be achieved by raising average yield by only 0.014 MT or 14 kg /ha of sorghum output in Zambia, through mix and scale efficiency improvements.

The MPI panel estimation results for the 2011 to 2022 period show that TFP for sorghum production declined by 21 percent, due to consistent TC deterioration across all regions. This is the main revelation of this research. TC improvement was associated with FISP E-voucher, exports and AEZ IIA. But the positive influence of these variables was insufficient. TFP decline was associated with population due to crowding-in effect from inefficient producers. TFP decline was also associated with rurality of most regions in Zambia due to poor production technology and absence of commercial consumer markets to stimulate demand and yield improvement. This was so significant in AEZ IIB.

However, there were limits to this research. The cross-regional heterogeneity and unknown data integrity from secondary sources could limit the accuracy of our findings. This warrants future re-examination of this topic. Overall, this study contributes to the broader literature, as the first publication in Zambia and SADC to evaluate regional TE and TFP for sorghum production over a 10-year period, covering varied agroecological zones (Table 7).

We recommend that appropriate measures should be taken to reverse the declining sorghum production and productivity trends, because it is an important economic subsector in agriculture, with potential for ensuring continued food production under climate change. Domestic and commercial sorghum utilization should be promoted to grow demand and ensure better rural incomes, food and nutrition security considering emerging demand for healthy diets in Zambia. Contract farming such as out-grower schemes should be promoted for self-motivated sorghum producers. Such schemes could help to create guaranteed markets for small and medium scale sorghum farmers in rural regions. Further, countrywide promotion of FISP E-voucher will ensure sorghum mainstreaming through improved access to inputs by self-motivated beneficiaries. Lastly, the technological wherewithal for sorghum producers should be improved upon through intensification of research and development (R&D) in climate smart agriculture (CSA) systems and practices in Zambia, and the SADC region.

Data availability

The data that support the findings of this study will be shared upon request.

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CRediT authorship contribution statement

Obed Chanda: Data curation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Conceptualization, Project administration. **Chieko Umetsu:** Conceptualization, Formal analysis, Funding acquisition, Investigation, Methodology, Resources, Software, Supervision, Validation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors report no conflict of interest to declare.

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Appendix

Table 7

Results from the FGLS Model for Factors Associated with Efficiency Change(EC), Technological Change(TC), and Malmquist Productivity Index (MPI) for Small and Medium Scale Sorghum Producers in Zambia.

	FGLS		
VARIABLES	lnEC	lnTC	lnMPI
Constant	13.358***	2.443	15.744***
	(5.018)	(1.981)	(4.290)
lnRainfall (mm)	0.018	−0.093*	−0.045
	(0.092)	(0.056)	(0.095)
lnPopulation (thousands)	−1.439***	−0.008	−1.423***
	(0.361)	(0.126)	(0.324)
lnLiteracy level (%)	1.680*	−0.420	1.162
	(0.914)	(0.352)	(0.764)

(*continued on next page*)

Table 7 (*continued*)

	FGLS		
VARIABLES	lnEC	lnTC	lnMPI
lnCompanies (no.)	−0.028	0.016**	−0.010
	(0.017)	(0.007)	(0.014)
lnSales volume (MT)	−0.035	0.015*	−0.019
	(0.025)	(0.009)	(0.019)
COVID19 (year=1)	0.305**	−0.079	0.205
	(0.149)	(0.061)	(0.135)
Rural (yes=1)	−0.543**	−0.024	−0.627**
	(0.276)	(0.097)	(0.245)
FISP E-Voucher (yes=1)	1.065**	0.073	1.118**
	(0.487)	(0.130)	(0.451)
FISP DIS (yes=1)	0.167	−0.369***	−0.235
	(0.160)	(0.066)	(0.144)
Export (yes=1)	0.567***	−0.118**	0.445***
	(0.128)	(0.052)	(0.110)
AEZI (yes=1)	−0.218	−0.124	−0.313
	(0.496)	(0.145)	(0.453)
AEZIIA (yes=1)	0.966***	−0.074	0.812***
	(0.265)	(0.094)	(0.228)
AEZIIB (yes=1)	−0.782***	0.072	−0.710***
	(0.138)	(0.074)	(0.127)
Observations	90	90	90
Number of DMUs	10	10	10

Significance indicated by *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
Source: Authors' estimation from ZamStats CFS & PDP, WFP data and others.

References

[1] J.R. Brown, D. Kluck, C. McNutt, M. Hayes, Assessing drought vulnerability using a socioecological framework, Rangelands 38 (4) (2016) 162–168, https://doi.org/10.1016/j.rala.2016.06.007. Aug.

[2] L. Connolly-Boutin, B. Smit, Climate change, food security, and livelihoods in sub-Saharan Africa, Reg. Environ. Change 16 (2) (2016) 385–399, https://doi.org/10.1007/s10113-015-0761-x. Springer VerlagFeb. 01,.

[3] M. Mumtaz, J. Antonio Puppim de Oliveira, S.H. Ali, Climate change impacts and adaptation in agricultural sector: the case of local responses in Punjab, Pakistan. Climate Change and Agriculture, IntechOpen, 2019, https://doi.org/10.5772/intechopen.83553.

[4] T.D. Mushore, T. Mhizha, M. Manjowe, L. Mashawi, E. Matandirotya, E. Mashonjowa, C. Mutasa, J. Gwenzi, M.G. Tawanda, Climate change adaptation and mitigation strategies for small holder farmers: a case of Nyanga district in Zimbabwe, Front. Climate 3 (2021), https://doi.org/10.3389/fclim.2021.676495.

[5] Lost Crops of Africa, National Academies Press, Washington, D.C., 1996, https://doi.org/10.17226/2305.

[6] P. Thornton, D. Dinesh, L. Cramer, A.M. Loboguerrero, B. Campbell, Agriculture in a changing climate: keeping our cool in the face of the hothouse, Outlook Agric. 47 (4) (2018) 283–290, https://doi.org/10.1177/0030727018815332. Dec.

[7] D. Zilberman, L. Lipper, N. McCarthy, and B. Gordon, Innovation in response to climate change, 2018, pp. 49–74. 10.1007/978-3-319-61194-5_4.

[8] Effects of the 1991-92 drought in Zambia.

[9] The 2015-16 El Niño-induced drought crisis in Southern Africa: lessons from historical data and policy implications.

[10] Chapter 3-Infectious diseases in Africa 37.

[11] S. Rajendran, V. Afari-Sefa, A. Shee, T. Bocher, M. Bekunda, I. Dominick, P. J. Lukumay, Does crop diversity contribute to dietary diversity? Evidence from integration of vegetables into maize-based farming systems, Agric. Food Secur. 6 (1) (2017) 50, https://doi.org/10.1186/s40066-017-0127-3.

[12] E.O. Alamu, T. Gondwe, T.E. Eyinla, B. Maziya-Dixon, Assessment of dietary diversity of mothers and children of 6–24 months from Eastern and Southern provinces of Zambia, J. Nutr. Metab. (2019) 1–9, https://doi.org/10.1155/2019/1049820, 2019Jul.

[13] W. Khalid, A. Ali, M.S. Arshad, F. Afzal, R. Akram, A. Siddeeg, S. Kousar, M. A. Rahim, A. Aziz, Z. Maqbool, A. Saeed, Nutrients and bioactive compounds of *Sorghum bicolor* L. used to prepare functional foods: a review on the efficacy against different chronic disorders, Int. J. Food Prop. 25 (1) (2022) 1045–1062, https://doi.org/10.1080/10942912.2022.2071293.

[14] A.G. Kulamarva, V.R. Sosle, G.S.V. Raghavan, Nutritional and rheological properties of sorghum, Int. J. Food Prop. 12 (1) (2009) 55–69, https://doi.org/10.1080/10942910802252148. Jan.

[15] J.K.P. Vanamala, A.R. Massey, S.R. Pinnamaneni, L. Reddivari, K.F. Reardon, Grain and sweet sorghum (*Sorghum bicolor* L. Moench) serves as a novel source of bioactive compounds for human health, Crit. Rev. Food Sci. Nutr. 58 (17) (2018) 2867–2881, https://doi.org/10.1080/10408398.2017.1344186. Nov.

[16] T.S. Abdelhalim, N.M. Kamal, A.B. Hassan, Nutritional potential of wild sorghum: grain quality of Sudanese wild sorghum genotypes (*Sorghum bicolor* L. Moench), Food Sci. Nutr. 7 (4) (2019) 1529–1539, https://doi.org/10.1002/fsn3.1002. Apr.

[17] A. Orr, C. Schipmann-Scwarze, A. Gierend, S. Nedumaran, C. Mwema, E. Muange, E. Manyasa, H. Ojulong, Why invest in research & development for sorghum and millets? The business case for East and Southern Africa, Glob. Food Sec. 26 (2020) 100458, https://doi.org/10.1016/j.gfs.2020.100458.

[18] Intsormil, Promoting Market Driven Sorghum Production in Zambia Promoting Market Driven Sorghum Production in Zambia, intsormil, 2008 [Online]Available: https://digitalcommons.unl.edu/intsormilimpacts/66.

[19] J. McCann, Maize and grace: history, corn, and Africa's new landscapes, 1500-1999, 43(2), pp. 246–72, 2001.

[20] B.F. Johnston, S.T. Nielsen, Agricultural and structural transformation in a developing economy, Econ. Dev. Cult. Change 14 (3) (1966) 279–301, https://doi.org/10.1086/450164. Apr.

[21] S. Wiggins, G. Argwings-Kodhek, J. Leavy, and C. Poulton, Small farm commercialisation in Africa: reviewing the issues, 2011. [Online]. Available: www.future-agricultures.org.

[22] E. Njeru, Crop diversification: a potential strategy to mitigate food insecurity by smallholders in sub-Saharan Africa, J. Agric. Food Syst. Commun. Dev. (2013) 1–7, https://doi.org/10.5304/jafscd.2013.034.006. Jul.

[23] V.O. Abegunde, M. Sibanda, A. Obi, The dynamics of climate change adaptation in sub-Saharan Africa: a review of climate-smart agriculture among small-scale farmers, Climate 7 (11) (2019) 132, https://doi.org/10.3390/cli7110132. Nov.

[24] Sustainable solutions to end hunger.

[25] M.O. Bushara, A.M. Mohammed Abuagla, Measuring production efficiency of sorghum small farmers in Rahad agricultural scheme season (2011-2012), J. Socialomic. 06 (01) (2017), https://doi.org/10.4172/2167-0358.1000192.

[26] E. Chepng'etich, S.O. Nyamwaro, E.K. Bett, K. Kizito, Factors that influence technical efficiency of sorghum production: a case of small holder sorghum producers in lower Eastern Kenya, Adv. Agric. (2015), https://doi.org/10.1155/2015/861919, 2015.

[27] A.M. Wakili, Technical efficiency of sorghum production in Hong local government area of Adamawa state, Nigeria, Russ. J. Agric. Socioecon. Sci. 6 (6) (2012) 10–15, https://doi.org/10.18551/rjoas.2012-06.02. Jun.

[28] S. Markos, T. Simion, T. Samuel, Evaluation of improved lowland sorghum (*Sorghum Bicolor* (L.) Moench) varieties in Southern Ethiopia, Cogent. Food Agric. 6 (1) (2020) 1727624, https://doi.org/10.1080/23311932.2020.1727624. Jan.

[29] Weldegebriel Hagos, The determinants of technical efficiency of farmers in teff, maize and sorghum production: empirical evidence from central zone of Tigray region, Ethiopian J. Econ. 23 (2) (2015) 1–36. Oct.

[30] A.C. Chipanshi, R. Chanda, O. Totolo, Vulnerability assessment of the maize and sorghum crops to climate change in Botswana, Clim. Change 61 (3) (2003) 339–360, https://doi.org/10.1023/B:CLIM.0000004551.55871.eb. Dec.

[31] T. Mabhaudhi, V. Chimonyo, A. Modi, Status of underutilised crops in South Africa: opportunities for developing research capacity, Sustainability 9 (9) (2017) 1569, https://doi.org/10.3390/su9091569. Sep.

[32] T. Muzerengi, H.M. Tirivangasi, Small grain production as an adaptive strategy to climate change in Mangwe District, Matabeleland South in Zimbabwe, Jamba: J. Disaster Risk Stud. 11 (1) (2019) 1–9, https://doi.org/10.4102/JAMBA.V11I1.652.

[33] L.M. Pereira, C. Hawkes, Leveraging the potential of sorghum as a healthy food and resilient crop in the South African food system, Front. Sustain. Food Syst. 6 (2022), https://doi.org/10.3389/fsufs.2022.786151. May.

[34] F. Dube, A. Mujeyi, M.P. Moyo, and O. Mukondwa, Advances in sorghum production in smallholder farming systems of Africa, 2023, pp. 187–205. 10.1007/978-981-99-2427-1_11.

[35] D. Dambala and G. Kutela, Agriculture, climate change and technical efficiency: the case of sub-Saharan Africa, 2022.

[36] B.C. Chimai, C.S. Thraen, D. Larson, and G. Tembo, Determinants of technical efficiency in smallholder sorghum farming in Zambia.

[37] M. Chisi, Impact assessment of sorghum research in Zambia. Impact of Science on African agriculture and Food Security, CABI, Wallingford, 2007, pp. 137–146, https://doi.org/10.1079/9781845932671.0137.

[38] L. Mbulwe, O.C. Ajayi, Case study – sorghum improvement in Zambia: promotion of sorghum open pollinated varieties (SOPVs), Eur. J. Agric. Food Sci. 2 (5) (2020), https://doi.org/10.24018/ejfood.2020.2.5.108. Oct.

[39] P. Hamukwala, G. Tembo, and D. Larson, Sorghum and pearl millet improved seed value chains in Zambia: sorghum and pearl millet improved seed value chains in Zambia: challenges and opportunities for smallholder farmers challenges and opportunities for smallholder farmers mark erbaugh. [Online]. Available: https://digitalcommons.unl.edu/intsormilpubs/3.

[40] P. Hamukwala, Improved seed variety value chains in Zambia: a missed opportunity to improve smallholder productivity, Afr. J. Agric. Res. 7 (34) (2012), https://doi.org/10.5897/ajar12.527. Sep.

[41] Transforming the farm input support programme (FISP) to diversified agroecology practices in Pemba District, Southern Province, Zambia Kasisi Agricultural Training Centre Promoting Sustainable Organic Agriculture Republic of Zambia.

[42] L. Mbulwe, M. Lwaile, and M. Chisi, Effectiveness of participatory breeding and variety selection for sorghum technology adoption in Zambia. [Online]. Available: https://www.researchgate.net/publication/277322652.

[43] Munacinga. Simatele, Food production in Zambia: the impact of selected structural adjustment policies, Afric. Econ. Res. Consort. (2006).

[44] J.P. Musara, L. Dube, B. Joyce, Debunking the sorghum- based stock feed final markets in Lusitu, Zambia: a critical success factor analysis approach, Greener J. Agric. Sci. 4 (7) (2014) 302–309, https://doi.org/10.15580/GJAS.2014.7.070814297. Aug.

[45] R. Mahadevan, To measure or not to measure total factor productivity growth? Oxford Dev. Stud. 31 (3) (2003) 365–378, https://doi.org/10.1080/1360081032000111742. Sep.

[46] A. Charnes, W.W. Cooper, E. Rhodes, Measuring the efficiency of decision-making units, Eur. J. Oper. Res. 2 (6) (1978) 429–444, https://doi.org/10.1016/0377-2217(78)90138-8. Nov.

[47] G. Katharakis, M. Katharaki, T. Katostaras, An empirical study of comparing DEA and SFA methods to measure hospital units' efficiency, Int. J. Oper. Res. 21 (3) (2014) 341, https://doi.org/10.1504/IJOR.2014.065413.

[48] W.F. Bowlin, Measuring performance: an introduction to Data Envelopment Analysis (DEA), J. Cost Anal. 15 (2) (1998) 3–27, https://doi.org/10.1080/08823871.1998.10462318. Nov.

[49] C. Thirtle, D. Hadley, R. Townsend, Policy-induced innovation in Sub-Saharan African agriculture: a multilateral Malmquist productivity Index approach, Dev. Policy Rev. 13 (4) (1995) 323–348, https://doi.org/10.1111/j.1467-7679.1995.tb00097.x. Dec.

[50] C. Umetsu, T. Lekprichakul, U. Chakravorty, Efficiency and technical change in the philippine rice sector: a Malmquist total factor productivity analysis, Am. J. Agric. Econ. 85 (4) (2003) 943–963, https://doi.org/10.1111/1467-8276.00499. Nov.

[51] T.J. Coelli, D.S.P. Rao, Total factor productivity growth in agriculture: a Malmquist index analysis of 93 countries, 1980–2000, Agric. Econ. 32 (1) (2005) 115–134, https://doi.org/10.1111/j.0169-5150.2004.00018.x. Jan.

[52] D. Headey, M. Alauddin, D.S.P. Rao, Explaining agricultural productivity growth: an international perspective, Agric. Econ. 41 (1) (2010) 1–14, https://doi.org/10.1111/j.1574-0862.2009.00420.x. Jan.

[53] R.D. Banker, A. Charnes, W.W. Cooper, Some models for estimating technical and scale inefficiencies in data envelopment analysis, Manage. Sci. 30 (9) (1984) 1078–1092, https://doi.org/10.1287/mnsc.30.9.1078. Sep.

[54] K. Tone, A slacks-based measure of efficiency in data envelopment analysis, Eur. J. Oper. Res. 130 (3) (2001) 498–509, https://doi.org/10.1016/S0377-2217(99)00407-5. May.

[55] D.W. Caves, L.R. Christensen, W.E. Diewert, The economic theory of index numbers and the measurement of input, output, and productivity, Econometrica 50 (6) (1982) 1393, https://doi.org/10.2307/1913388. Nov.

[56] S. Malmquist, Index numbers and indifference surfaces, Trabajos de Estadistica 4 (2) (1953) 209–242, https://doi.org/10.1007/BF03006863. Jun.

[57] R. Färe, S. Grosskopf, M. Norris, and Z. Zhang, American economic association productivity growth, technical progress, and efficiency change in industrialized countries, 1994.

[58] R. Färe, S. Grosskopf, and M. Norris, American economic association productivity growth, technical progress, and efficiency change in industrialized countries, 1997.

[59] S. Rahman, R. Salim, Six decades of total factor productivity change and sources of growth in Bangladesh agriculture (1948-2008), J. Agric. Econ. 64 (2) (2013) 275–294, https://doi.org/10.1111/1477-9552.12009. Jun.

[60] O. Temoso, J.N. Ng'ombe, S. Bahta, D. Hadley, Total factor productivity growth in livestock production in Botswana: what is the role of scale and mix efficiency change in beef production? Agrekon 62 (1) (2023) 5–18, https://doi.org/10.1080/03031853.2022.2156899.

[61] A. Bell, K. Jones, Explaining fixed effects: random effects modelling of time-series cross-sectional and panel data, Polit. Sci. Res. Methods 3 (1) (2015) 133–153, https://doi.org/10.1017/psrm.2014.7. Jan.

[62] O. Torres-Reyna, panel data analysis fixed and random effects using Stata (v. 4.2), 2007. [Online]. Available: http://dss.princeton.edu/training/.

[63] N. Beck, J.N. Katz, What to do (and not to do) with time-series cross-section data, Am. Polit. Sci. Rev. 89 (3) (1995) 634–647, https://doi.org/10.2307/2082979. Sep.

[64] Baltagi, *Econometric Analysis of Panel Data*.

[65] H. Greene William, Econometric Analysis, 2003.

[66] Bradley Effron, Robert Tibshirani, An Introduction to the Bootstrap, 1993.

[67] B. Efron, Bootstrap methods: another look at the jackknife, Annal. Stat. 7 (1) (1979), https://doi.org/10.1214/aos/1176344552. Jan.

[68] J. Mtambo, M. Madder, W. Van Bortel, G. Chaka, D. Berkvens, T. Backeljau, Further evidence for geographic differentiation in R. appendiculatus (Acari: ixodidae) from Eastern and Southern provinces of Zambia, Exp. Appl. Acarol. 41 (1–2) (2007) 129–138, https://doi.org/10.1007/s10493-007-9049-2. Feb.

[69] D.J. Megill, Recommendations on sample design for post-harvest surveys in Zambia based on the 2000 census, 2004. [Online]. Available: http://www.aec.msu.edu/agecon/fs2/zambia/index.htm.

[70] D.J. Megill, food security research project recommendations for adjusting weights for Zambia post-harvest survey data series and improving estimation methodology for future surveys, 2005. [Online]. Available: http://www.aec.msu.edu/agecon/fs2/zambia/index.htm.

[71] B. Golany, Y. Roll, An application procedure for DEA, Omega (Westport) 17 (3) (1989) 237–250, https://doi.org/10.1016/0305-0483(89)90029-7. Jan.

[72] A. Boussofiane, R.G. Dyson, E. Thanassoulis, Applied data envelopment analysis, Eur. J. Oper. Res. 52 (1) (1991) 1–15, https://doi.org/10.1016/0377-2217(91)90331-O. May.

[73] Y.M. Baion, W. Yunxia, E.H. Foday, C. Jianmin, L. Chuanfu, O. Agyeman, Comparative performance of agricultural productivity in 44 SSA countries for a period of 59 years (1961–2019): a Malmquist productivity index approach, PLoS ONE 18 (7) (2023) e0284461, https://doi.org/10.1371/journal.pone.0284461. Jul.

[74] A. Onoja, Give to AgEcon search, 2021. [Online]. Available: http://ageconsearch.umn.edu.

[75] L.W. Myeki, Y.T. Bahta, N. Matthews, Exploring the growth of agricultural productivity in Africa: a Färe-Primont index approach, Agriculture 12 (8) (2022) 1236, https://doi.org/10.3390/agriculture12081236. Aug.

[76] E. Chepng'etich, S.O. Nyamwaro, E.K. Bett, K. Kizito, Factors that influence technical efficiency of sorghum production: a case of small holder sorghum producers in lower Eastern Kenya, Adv. Agric. (2015) 1–11, https://doi.org/10.1155/2015/861919, 2015.

[77] M.A. Yahaya, H. Shimelis, B. Nebie, C.O. Ojiewo, G. Danso-Abbeam, Sorghum production in Nigeria: opportunities, constraints, and recommendations, Acta Agric. Scand. B Soil. Plant Sci. 72 (1) (2022) 660–672, https://doi.org/10.1080/09064710.2022.2047771. Dec.

[78] N.T. Muzeza, A. Taruvinga, P. Mukarumbwa, Analysis of factors affecting technical efficiency of A1 smallholder maize farmers under command agriculture scheme in Zimbabwe: the case of Chegutu and Zvimba Districts, Cogent. Econ. Finance 11 (1) (2023), https://doi.org/10.1080/23322039.2022.2163543. Dec.

[79] M. Siame, I. Lichilo, N. Siame, An assessment of FISP e-voucher performance, Int. J. Innovat. Res. Dev. 6 (7) (2017). Jul. 10.24940/ijird/2017/v6/i7/116583-270349-2-sm.

[80] N.M. Mason, A. Kuteya, H. Ngoma, D.A. Tossou, and K.R. Baylis, Feed the future innovation lab for food security policy did the e-voucher approach to Zambia's Farmer Input Support Programme (FISP) outperform the traditional FISP? Evidence from the crop forecast surveys.

[81] D.A. Tossou and K.R. Baylis, Does flexibility in agricultural input subsidy programs improve smallholder crop yields and household food security? Evidence from Zambia, 2018.

[82] S. Mustapha, Fertiliser subsidy and technical efficiency of smallholder farmers in selected districts in the transitional and the Guinea Savannah Zones of Ghana, SSRN Electron. J. (2016), https://doi.org/10.2139/ssrn.2866944.

[83] J. Wang, P. Han, The impact of industrial agglomeration on urban green land use efficiency in the Yangtze river economic belt, Sci. Rep. 13 (1) (2023), https://doi.org/10.1038/s41598-023-28250-7. Dec.

[84] A.A. Ogundipe, E.A. Oduntan, O. Adebayo, K.O. Olagunju, Agricultural productivity, poverty reduction and inclusive growth in Africa: linkages and pathways, SSRN Electron. J. (2016), https://doi.org/10.2139/ssrn.2856449.

[85] C. Ragasa, J. Mazunda, The impact of agricultural extension services in the context of a heavily subsidized input system: the case of Malawi, World Dev. 105 (2018) 25–47, https://doi.org/10.1016/j.worlddev.2017.12.004. May.

[86] L. Tang, J. Zhou, I. Bobojonov, Y. Zhang, T. Glauben, Induce or reduce? The crowding-in effects of farmers' perceptions of climate risk on chemical use in China, Clim. Risk Manag. 20 (27–37) (2018), https://doi.org/10.1016/j.crm.2018.02.001.

[87] B.T. Bekata, Ch.Appa Rao, G. Nagaraja, Effects of agricultural market imperfections on rural multidimensional poverty: evidence from the Sidama region of Ethiopia, Cogent. Food Agric. 9 (2) (2023), https://doi.org/10.1080/23311932.2023.2273631. Dec.

[88] D.M. Okello, J. Bonabana-Wabbi, B. Mugonola, Farm level allocative efficiency of rice production in Gulu and Amuru districts, Northern Uganda, Agric. Food Econ. 7 (1) (2019) 19, https://doi.org/10.1186/s40100-019-0140-x. Dec.

[89] H.G. Hunga, L. Chiwaula, W. Mulwafu, M. Katundu, The seed sector development in low-income countries: lessons from the Malawi seed sector policy process, Front. Sustain. Food Syst. 7 (2023), https://doi.org/10.3389/fsufs.2023.891116. Mar.

[90] Linzi Lewis and Sabrina Masinjila, Status report on the SADC, COMESA and EAC Harmonised seed trade regulations: where does this leave the regions' smallholder farmers? Johannesburg, 2018.