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The effect of agricultural technology transfer on Zimbabwe's economic development: a dynamic global trade analysis project approach

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ABSTRACT
Since 2000, Zimbabwe's agricultural output has fluctuated despite the transfer of agricultural technology by various organisations and international partners. The low output response to technology transfer is attributed to the twin problems of lack of access and adoption of technology, which are largely explained by weak institutions, financial constraints, skill and knowledge deficiency, and poor rural infrastructure. The aim of this study was therefore to assess the effect of agricultural technology transfer on economic development using a dynamic Global Trade Analysis Project model for the reference year 2011. The study results indicated that economic performance improves when quality fertilisers, certified seeds, and machinery from other countries are used more intensively. Thus, policy interventions are required that enhance credit extension, roads, capital equipment, and good institutions such as property rights that incentivise farmers to adopt and invest in technology.

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1. Introduction

Zimbabwe's diverse climatic conditions enable it to cultivate a wide range of food and cash crops, and its agricultural sector provides food for its citizens and employment to 70% of the population, making it a crucial economic sector. However, substantial obstacles prevent the sector from becoming sustainable and enhancing people's standard of living. Zimbabwe faced unprecedented macroeconomic instability and a substantial economic decline from 1999 to 2008 (Echanove 2017). After the land reform programme of 2000, farm structures were redistributed such that approximately 98% of the country's farmers are smallholders who lack farming skills and adequate knowledge of climate change adaptation measures (Echanove 2017). As a result, the country is incompetent, has low productivity, and has limited market access. After the adoption of a multicurrency regime in 2009, the economy began its transition to growth. As agriculture is a significant industry in Zimbabwe, efforts have been made to increase its productivity through local policy frameworks and assistance programmes. For example, the Zimbabwe Agenda for Sustainable Socio-Economic Transformation (ZimASSET) blueprint (2013–18) centred on empowering society and eradicating poverty via human capital development. The ZimASSET input support programme was responsible for distributing government-supplied improved seeds (Government of Zimbabwe 2012). However, not all small-scale farmers had access to these seeds, and despite the programme, production and

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productivity continued to decline. In addition, Zimbabwe's distorted markets present obstacles for smallholder farmers. Every year, households that rely on subsistence and commercial agriculture practice farming, but the yield varies from year to year due to climate changes, with one good season every four years (Government of Zimbabwe 2018). Due to the population's reliance on agriculture, there is an urgent need for new technology, such as tools and techniques that can increase crop yield, adapt to unpredictable climatic conditions, and make routine farm activities more effective and efficient.

Zimbabwe has recognised the threats to its food security and economic development and has embraced South-South cooperation by partnering with China and incorporating China's experiences with smallholder farmer empowerment, post-harvest loss management, and rural transformation (World Food Programme 2017). Under the Forum for China–Africa Cooperation (FOCAC), China also aims to strengthen the capacity-building and technology transfer of African countries (Ministry of Commerce, People's Republic of China, 2018). Adopting agricultural technology such as soil and water sensors, weather tracking, irrigation, conservation agriculture, fertiliser or manure application, and satellite imaging has the potential to revolutionise the Zimbabwean agricultural sector. The scope of technology encompasses a variety of concepts, such as training and extension of knowledge (Kuijpers and Swinnen 2016). According to researchers, technology is the systematic application of scientific or other organised knowledge to practical tasks. Cantwell and Qui (2009) defines technology as anything, tangible or intangible, that could contribute to the economic, industrial, or cultural development of a country, regardless of whether that technology is currently available to the country. Conversely, technological transfer involves the transfer of know-how, information, and technical knowledge pertaining to products, processes, and management (Wahab, Rose, and Osman 2011). Increasing agricultural productivity can be accomplished through the adoption and transfer of technology in the form of high-yield or disease-resistant crops, manufactured inputs, machinery, management techniques, and university research and training(Anderson 1989; Yu and Wu 2018) and reduce production costs. Greater productivity and lower production costs will reduce consumer prices, resulting in a lower cost of living and less inflationary pressure, both of which are significant challenges for Zimbabwe.

Since the international community recognises agriculture as the engine of economic growth, Zimbabwe has prioritised accelerating the rate of agricultural expansion. Countries such as China have pledged assistance in the form of agricultural technologies to improve the performance of Zimbabwe's agricultural sector by extending agricultural technologies through practical field demonstrations and enhancing farming practices (Ministry of Commerce, People's Republic of China, 2018). In some nations, the adoption of technology has also increased productivity, decreased poverty, and decreased food prices (Anderson 1989). The puzzling persistence of poor economic performance and widespread poverty in Zimbabwe, despite the availability of technological means, necessitates pragmatic solutions. However, given the rate at which China transfers technology to Africa, it is necessary to evaluate the impact of the agricultural technology transfer on Zimbabwe's economic growth.

Command Agriculture was established to provide large-scale farmers with inputs, as well as irrigation and mechanised equipment from Brazil, Belarus, Russia, and India, on the condition that they repay the government with the maize they harvest. This was done to facilitate the recovery from a Farm Mechanisation Scheme that had failed due to poor governance (Echanove 2017). Small-scale farmers were not catered for by the Command Agriculture Programme, which encountered funding and governance difficulties. Other programmes included the 2014 Climate Change Response Strategy and the 2015 Nationally Determined Contribution, which focused on promoting climate adaptation through indigenous and scientific knowledge and technologies. In addition to local programmes, other nations offered assistance to improve Zimbabwe's economic situation, including the agricultural sector. For instance, the United States Agency for International Development (USAID) provided assistance centred on agricultural productivity, whereas the European Union (EU) supported agricultural extension services and productivity growth with a focus on irrigation and livestock for smallholder farmers. In addition, China has implemented modern technologies such as irrigation, chemical inputs, genetically modified crops, and mechanised machinery, and it is working to transfer these technologies to all of Africa, including Zimbabwe. The $30 million Agricultural Demonstration Centre at Gwebi Agricultural College is evidence of Zimbabwe's dependence on China for technological advancement (Alao 2014).

Figure 1 indicates that the agricultural output of Zimbabwe has fluctuated, reaching a peak of approximately 18 million tonnes in 2004. This low agricultural productivity indicates that the available aid has had little effect (Government of Zimbabwe 2012), and while Zimbabwe was once the breadbasket of the Southern African Development Community, it is now a net importer of some commodities it can produce.

Zimbabwe is endowed with arable land, and its agricultural output should always be sufficient to meet national needs. Nevertheless, despite the assistance provided, agricultural productivity has remained stagnant, primarily because smallholder farmers lack access to new technologies. Zimbabwe is still a net importer of a wide variety of agricultural products, despite the fact that countries like China have made concerted efforts to expand agricultural technologies. Prior research in Zimbabwe concentrated on the effects of agricultural technologies on agricultural output and food security (Snapp et al. 2002; Nyagumbo et al. 2009; Muzari et al. 2013; Masere and Worth 2021). In addition, studies utilising a dynamic computable general equilibrium (CGE) model have been conducted to assess the effects of various economic policies. Takeda (2001) analysed two policy scenarios involving the transfer of technology for local coal-fired electricity generation from Japan to China in order to reduce CO2 emissions in China using a recursive dynamic CGE model. The study discovered that technology transfer by parameter reduced CO2 emissions more than technology transfer by structural change, and that adopting technology via capital and technology transfer would also reduce CO2 emissions. Anderson and Jackson (2004) utilised the Global Trade Analysis Project (GTAP) CGE model to evaluate the potential economic effects of adopting genetically modified crop varieties to increase profitability and satisfy consumer interests in developing nations. They discovered that countries in sub-Saharan Africa that were willing to adopt new crop varieties would benefit economically and not be negatively affected. To the researchers' knowledge, however, no research has been conducted using a CGE model to assess the impact of agricultural technology transfer on Zimbabwe's economy. Consequently, this study sought to fill this void. The study employed a recursive dynamic GTAP CGE model to determine the effect of agricultural technology transfer on Zimbabwe's economic development by increasing the level of technology used by agriculture and agro-based processing sectors that are linked to agriculture via backward

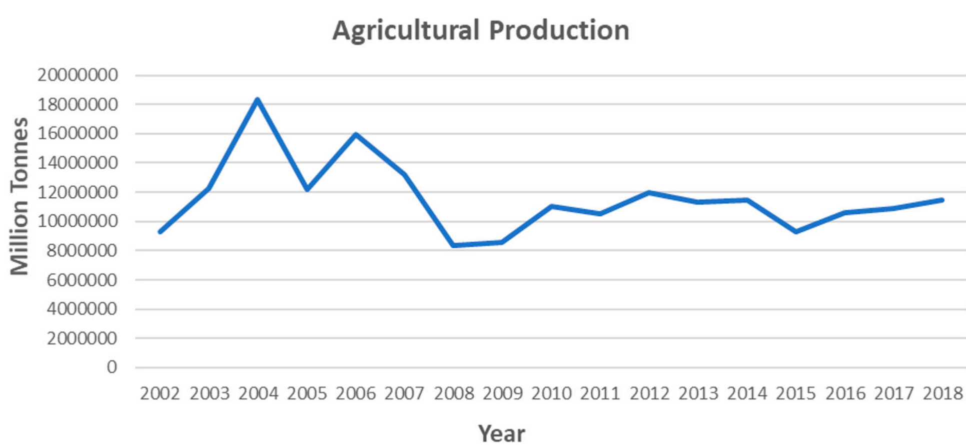

Figure 1. Zimbabwe's total agricultural production.

Source: Authors' compilation from the Food and Agriculture Organization of the United Nations (2019).

or forward links. The research hypothesised that the current level of technology utilisation is insufficient. Therefore, we sought to determine if increasing the use of technology is the key to developing Zimbabwe's economy or if other factors must also be considered.

The rest of the paper is structured as follows: Section 2 explains the methodology and data used for analysis; Section 3 describes the baseline scenario prior to any policy shock; Section 4 describes the policy simulation principles in detail; Section 5 discusses and Section 6 concludes, summarise the results, and provide recommendations.

2. Methodology and data sources

2.1 Methodology

To evaluate the effect of agricultural technology transfer on Zimbabwe's economic growth in 2011, the researchers employed a recursive dynamic GTAP CGE model. The model assumes perfect competition and constant returns on scale. Applied general equilibrium models are well-suited for results analysis as a result of their capacity to simultaneously analyze regions (Hertel 1997). Other models, such as econometric simulations, are unable to account for their ability to simplify economic behaviour and permit in-depth analysis of diverse economic issues. Through their numerical calculations, the models enable researchers to forecast changes in economic variables to represent what the economy would look like if, for example, economic policy and technology were modified (Hertel, Keeney, and Winters 2006).

2.2 Data sources

The data used in the model was obtained from the GTAP databases for the 2011 reference year, which include 57 commodities and 40 regions. Table 1 displays the narrowed aggregation resulting from the remapping of the 140 regions into six regions, with specific countries disaggregated as follows: Zimbabwe as the evaluable nation, China and South Africa as Zimbabwe's top trading partners, and the United States and European Union (including the United Kingdom) as Zimbabwe's top bilateral donors (USAID 2016). The remainder of the world was comprised of all other nations. The sectorial aggregation was remapped from 57 to 25 commodities, with agriculture and agro-based processing sectors disaggregated into single sectors and extraction, manufacturing, and services sectors aggregated into their respective industries. Land, labour (skilled and unskilled), capital, and natural resources were mapped to the four factor endowments. The mobility of labour and capital across sectors was assumed.

Table 1. Model aggregation.

Regions	Sectors		Factor endowments
Zimbabwe	Paddy rice	Wool, silk	Land
China	Wheat	Vegetable oils and fats	Labour
South Africa	Cereal grains	Beverages and tobacco products	Capital
United States of America	Cattle	Meat	Natural resources
Rest of the world	Dairy	Dairy products	
	Oilseeds		
	Sugar cane, beet	Sugar	
	Cotton	Processed rice	
	Other crops	Food products	
	Vegetables, fruits, nuts	Wood products	
	Raw milk	Mining and extraction	
	Forestry	Manufacturing	
	Fishing	Services	
	Animal products		

Source: Authors' aggregation.

Moreover, the 2011 data from the GTAP9 database was forecasted to provide an economic overview of all the years since 2011 as well as the periods under study, i.e., 2020–30. The macroeconomic data was obtained in terms of growth rates from the following sources:

A. The gross domestic product (GDP) was obtained from the CEPII (Fouré, Bénassy-Quéré, and Fontagné 2013) and United Nations Conference on Trade and Development (UNCTAD 2019).
B. Population, private consumption, and government expenditure were obtained from the World Bank database. Private consumption expenditure was obtained as the annual growth percentage of the expenditure of households and non-profit institutions serving households. Government expenditure was obtained as the annual growth percentage of general government final consumption expenditure (World Bank 2019e).
C. The investment growth rate was obtained as a percentage of the GDP from the International Monetary Fund and the World Economic Outlook (International Monetary Fund 2019).
D. All other variables were obtained from the World Bank database:
   - land was proxied by the percentage of arable land (World Bank 2019a);
   - capital stock was proxied by Gross Capital Formation (World Bank 2019b);
   - labour data was obtained as the total national estimates of the labour force participation rate for ages 15 years and above (World Bank 2019c); and
   - natural resources were proxied by total natural resource rents as a percentage of GDP (World Bank 2019d).

The majority of the collected data was only available through 2017 or 2018, so Microsoft Excel was used to generate projections for 2019–2030.

3. Baseline scenario

3.1 Scenario without any policy shock

The macroeconomic indicators of interest to this study are depicted in Table 2 as a result of the baseline simulation. This is what the Zimbabwean economy would look like if no policies were implemented. The Gross Domestic Product, which measures the overall performance of the economy, indicates that economic growth will continue to decline from 2020, with a decrease of 4.1% in 2030. The decline in economic growth can also be attributed to negative total consumption, which would also affect the moderate CPI inflation rate. The volume of exports and imports would diminish over time. The export volume would be greater than the import volume, as evidenced by a positive trade balance between 2020–30. The total consumption would be negative and fall further. The savings would be positive but would decline. The rate of return would be entirely negative, indicating a lack of investment and savings. Additionally, the income generated from capital equity demonstrates that the rate of return would lead to a decline in investment. Welfare would be negative, indicating reduced regional welfare in all years, with the largest welfare loss in 2030 amounting to US$451.05 million.

4. Policy simulation

4.1 Policy simulation scenarios

Considering China's willingness to assist Africa through technology transfer under FOCAC and Zimbabwe's readiness to adopt some of China's agricultural technology, the study created two scenarios to assess the effect of the policy:

1. **Policy simulation scenario 1**: a 10% increase in the use of certified seeds, high-quality fertilisers, and agricultural machinery.

Table 2. Baseline results without any policy implemented.

Variables	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
GDP (%)	0.81	0.37	−0.39	−1.57	−1.07	−2.08	−2.59	−3.04	−3.37	−3.64	−4.1
RTS	6.02	4.68	3.26	1.73	1.29	0.06	−0.88	−1.75	−2.52	−3.26	−4.17
Imports (%)	−1.67	−1.81	−2.17	−3.17	−2.21	−3.16	−3.54	−3.93	−4.28	−4.61	−5.27
Trade balance US$ millions	501.16	462.02	410.31	380.48	289.95	260.64	209.22	161.95	121.31	81.87	51.55
Welfare effect US$ millions	−252.23	−284.22	−331.7	−418.41	−355.5	−423.66	−441.99	−452.74	−453.46	−446.94	−451.05
Savings (%)	1.26	1.25	1.1	1.03	0.97	0.94	0.91	0.93	0.99	1.07	1.18
Rate of return (%)	−0.17	−0.05	−0.22	−0.88	−0.12	−0.88	−1.23	−1.62	−1.97	−2.35	−3
Total consumption (%)	−3.83	−4.6	−6.03	−8.43	−7.24	−9.34	−10.27	−11.02	−11.49	−11.69	−12.13
Consumer price index (%)	1.18	1.21	1.11	1.08	1.07	1.07	1.11	1.2	1.34	1.54	1.83

Source: Authors' simulation.

2. **Policy simulation scenario 2**: a 30% increase in the use of certified seeds, high-quality fertilisers, and agricultural machinery.

Due to the difficulty in measuring the current level of available technology and the fact that Zimbabwe has benefited from donor assistance in the agricultural sector, this study proposed two policy simulation scenarios involving a 10% and 30% increase on the unknown level of available technology. This is because the current level of certified seeds, high-quality fertilisers, and agricultural machinery is insufficient, as evidenced by the sector's lack of progress, it was proposed that these simulations be conducted to examine the effects of increasing the amount of these resources. Comparing each policy to the baseline simulation scenario, the study determined whether increasing the level of technology used in Zimbabwe's agriculture and agro-based processing sectors would be beneficial to the economy and which level would yield the greatest benefit. According to the law of diminishing returns, increasing one unit of a factor will eventually cause marginal productivity to decrease. This implies that a continued increase in skilled labour would eventually result in a decline in agricultural sector productivity, all else being equal. Consequently, the results of the policy simulation reveal whether the low to medium (scenario 1) or high (scenario 2) use of certified seeds, high-quality fertilisers, and agricultural machinery transferred and adopted would benefit the country's sector, or if other factors besides adopting technology would lead to improved development of the agricultural sector and, consequently, economic growth.

4.2 Simulation principles

The study shocked an exogenous variable denoted by $ao_{(j,r)}$, which represents the technical change aimed at increasing output by improving labour skills. The shock was applied to all agriculture and Agro-based processing sectors in Zimbabwe, assuming that China would transfer its technology and Zimbabwe would adopt it.

Equation:

$$ao_{(j,r)} = \frac{-qva_{(j,r)} - ava_{(j,r)} + qo_{(j,r)} + ESUBT_{(j)}(-pva_{(j,r)} + ava_{(j,r)} + ps_{(j,r)})}{1 - ESUBT_{(j)}},$$

Source: (GTAP Database 2011)

where $ao_{(j,r)}$ is the output augmenting technical change in sector j or r; $qva_{(j,r)}$ is the value added in industry j of region r; $ava_{(j,r)}$ represents the value added by augmenting technical change in sector j of r; $qo_{(j,r)}$ is the industry output of commodity i in region r; $ESUBT_{(j)}$ is the elasticity of substitution among composite intermediate inputs in production; $pva_{(j,r)}$ shows the firms' price of value added in industry j of region r; and $ps_{(j,r)}$ is the supply price of commodity i in region r.

5. Policy simulation results

5.1 Effect on macroeconomic variables

In both policy simulation scenarios, the macroeconomic variables point to a strengthening of the Zimbabwean economy. Table 3 demonstrates a vastly greater improvement in scenario 2 of policy simulation than in scenario 1 of policy simulation. The positive GDP growth from 2020–30 in both scenarios compared to the baseline indicates that increasing the use of technology would improve the performance of the economy. This is consistent with Grabowski and Self (2006) assertion that agricultural technology promotes economic growth. In policy simulation scenario 1, the rise in the GDP is reflected in the rise in total government and household consumption over all time periods, which in turn influences the rise in the CPI over time, except in 2020. In some time periods, the volume of imports would rise more than the volume of exports in order to meet domestic and intermediate demand (2020–24). In both scenarios, this would result in both trade deficits

Table 3. Macroeconomic variables.

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
10% scenario											
GDP	5.37	6.44	7.34	8.24	9.45	10.33	11.19	11.91	12.47	12.93	13.21
Total consumption	12.13	14.47	16.2	17.9	20.2	21.87	23.48	24.81	25.86	26.67	27.05
Savings	1.99	2.1	2.29	2.55	2.94	3.26	3.6	3.9	4.16	4.4	4.58
Rate of return	2.74	2.45	2.29	2.2	2.25	2.14	2.02	1.85	1.63	1.42	1.22
Consumer price index	−0.53	−0.09	0.31	0.75	1.29	1.74	2.14	2.44	2.65	2.77	2.77
Exports	1.44	2.47	3.53	4.66	6.28	7.45	8.64	9.64	10.45	11.01	11.19
Imports	4.04	4.76	5.43	6.23	7.48	8.45	9.49	10.44	11.28	12.03	12.64
Trade balance US$ millions	−180.55	−161.83	−128.21	−85.2	−45.86	4.89	49.99	87.46	113.36	117.45	95.52
Welfare effect US$ million	525.02	592.18	635.17	656.95	718.69	731.59	752.57	766.51	778.51	791.98	779
30% scenario											
GDP	18.76	28.16	37.08	41.83	44.63	45.42	46.29	47.15	48.06	49.06	50.03
Total consumption	42.97	61.59	76.05	80.64	81.28	79.1	78.5	79.68	82.51	86.22	89.82
Savings	6.59	9.92	14.25	17.72	20.55	22.76	24.65	25.95	26.7	27	26.89
Rate of return	0.38	5.46	10.72	13.92	15.59	16.34	16.67	16.53	15.91	14.86	13.37
Consumer price index	20.42	29.33	40.57	47.72	52.36	54.17	55.43	56.02	56.33	56.73	57.38
Exports	5.67	15.45	30.04	41.11	48.17	50.12	51.17	51.28	51.01	50.81	50.77
Imports	14.3	23.73	34.47	39.17	39.97	39.58	40.9	43.93	48.25	53.25	58.4
Trade balance US$ millions	−598.3	−755.48	−829.01	−644.51	−206.47	395.49	771.68	228.5	−2366.57	−8992.47	−23153.5
Welfare effect US$ million	1641.88	2137.15	2638.34	3076.85	3801.17	4515.16	5842.16	8281.49	12693.01	20239.49	32318.61

Source: Authors' simulation

and surpluses. Scenario 2 of the policy simulation would result in trade deficits from 2020 to 2024 and from 2028 to 2030, with the largest deficit amounting to US$23,153.5 million in 2030. In scenario 1 of the policy simulation, the economy would experience deficits from 2020–24, with a trade deficit of US$180.55 million in 2020. The highest trade surplus in scenario 1 of the policy simulation would be US$117.45 million in 2029.

The moderate rate of return that would occur, with the highest being 2.74% in scenario 1 and 16.67% in scenario 2, would encourage investment. Consequently, based on the economic assumption that savings equals investment, this would increase savings. According to Thirtle, Lin, and Piesse (2003), research-driven technological change increases productivity, resulting in high rates of return. In both policy simulation scenarios, welfare would increase, but the increase would be significantly greater in policy simulation scenario 2, with welfare gains reaching up to US$32,318.61 million, than in policy simulation scenario 1, with welfare gains reaching up to US$779 million. This finding concurs with Grabowski and Self (2006) who conclude that agricultural technology enhances human development, thereby enhancing the population's well-being.

5.2 Effect on agricultural and agro-based sectors

As expected, Table 4 demonstrates that increasing the use of certified seeds, high-quality fertilisers, and agricultural machinery would increase sectoral output and, consequently, total output. This in turn explains some of Table 3′s results. As shown in Table 3, an increase in sectoral outputs would result in higher export volumes, with the greatest increases occurring in 2028 for policy simulation scenario 1 and in 2027 for policy simulation scenario 2, respectively. The increased export volumes also account for the increased GDP expansion. However, the total output would not increase by as much as the total consumption, because the rise in total consumption would lead to an increase in the CPI. In scenario 2 of policy simulation, output in the wheat, beverages, and tobacco sectors would decrease from 2025–30 and 2025–28, respectively, whereas in scenario 1 of policy simulation, output would increase throughout the years. According to Kuijpers and Swinnen (2016), the low productivity of certain crops is the result of the government prioritising certain crops over others and a lack of government financial support for cash crops such as cotton and wheat.

5.3 Effect on non-agricultural sectors

Table 5 demonstrates that an increase in the use of certified seeds, high-quality fertilisers, and agricultural machinery would have a positive effect on the service sectors because the output would increase as the use of technology increased; consequently, these sectors would benefit more from scenario 2 of the policy simulation. However, policy simulation scenario 2 would have a negative relationship with the output of the extraction and manufacturing sectors, as these sectors' outputs would decrease in both policy simulation scenarios, with the decrease in scenario 2 being greater.

5.4 Value added in industries

Table 6 demonstrates that more value would be added to the paddy rice sector under policy simulation scenario 1 than under policy simulation scenario 2, despite annual decreases. The wheat sector would benefit from the added value in 2020–23 under scenario 1 of policy simulation and in 2020 under scenario 2 of policy simulation, but the value-added would decrease for all other years, with the greatest decrease occurring under scenario 2 of policy simulation. In both policy simulation scenarios, the other cereal grains sector would experience a decline in value-added, with substantial losses in policy simulation scenario 2. The vegetables, fruits, and nuts sector would gain 0.38% in value during the first period under scenario 1 of policy simulation, but lose value over all periods

Table 4. Industry output in agriculture and agri-based processing sectors.

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
10% scenario											
Paddy rice	27.85	22.93	19.47	16.41	14.53	11.99	10	8.41	7.41	6.94	7.25
Wheat	15.49	12.01	10.65	9.77	9	8.05	7.14	6.36	5.79	5.34	5.1
Other cereal grains	7.1	6.85	6.9	6.98	7.18	7.15	7.11	7.04	6.97	6.9	6.79
Vegetables, fruit, nuts	10.37	9.2	8.67	8.19	8	7.42	6.94	6.47	6.07	5.76	5.46
Oilseeds	7.57	6.58	6.54	6.7	6.66	6.75	6.86	7.1	7.46	7.98	8.86
Sugar cane, sugar beet	37.7	29.04	22.86	18.08	15.75	13.18	11.71	10.84	10.41	10.28	10.24
Plant-based fibres	14.35	9.15	7.04	5.73	5.28	4.41	3.95	3.71	3.64	3.74	3.91
Other crops	15.79	11.72	10.02	8.66	7.89	6.55	5.46	4.56	3.91	3.43	3.15
Cattle, sheep, goats, horses	7.86	8.94	10.69	12.57	14.22	14.7	14.47	13.74	12.83	11.87	10.75
Raw milk	5.53	7.68	12.72	18.68	22.78	23.01	21.11	18.58	16.24	14.19	12.2
Forestry	10.43	11.34	11.66	11.48	11.19	10.47	9.77	9.1	8.53	8.05	7.62
Fishing	8.08	8.64	9.01	9.34	9.69	9.96	10.19	10.36	10.45	10.44	10.29
Animal products nec	10.9	11.71	13.62	15.46	16.88	16.65	15.75	14.52	13.32	12.22	11.08
Wool, silk-worm cocoons	1487.28	170.75	34.8	13.33	10.13	5.21	3.24	1.91	1.04	0.33	−0.84
Meat: cattle, sheep, goats, horse	31.67	40.7	51.95	57.84	57.21	51.16	44.55	38.79	34.29	30.79	27.72
Meat products nec	34.94	33.25	32.16	30.98	28.74	27.6	26.55	25.97	25.78	25.99	26.92
Vegetable oils and fats	18.1	20.53	26.41	33.17	37.63	37.28	34.62	31.36	28.44	25.91	23.49
Dairy products	35.6	33.91	33.37	32.94	30.57	30.05	29.39	29.17	29.29	29.68	30.66
Processed rice	51.83	42.17	35.21	29.77	27.22	24.22	22.49	21.41	20.82	20.56	20.35
Sugar	11.88	12.38	12.92	13.43	13.54	13.68	13.67	13.71	13.84	14.08	14.57
Food products nec	9.65	10.17	10.48	10.74	10.63	10.72	10.71	10.75	10.83	10.94	11.18
Beverages and tobacco products	32.04	34.73	35.65	34.66	32	28.82	25.38	22.33	19.84	17.72	16.31
Total output	1892.01	554.38	422.8	404.91	396.72	369.03	341.06	316.19	297.2	283.14	273.06
30% scenario											
Paddy rice	78.51	46.53	32.44	25.45	24.79	22.92	22.09	20.85	19.02	16.7	13.6
Wheat	37.11	21.59	12.69	6.37	1.93	−0.51	−1.76	−1.87	−1.71	−2.17	−2.98
Other cereal grains	20.01	19.58	19.03	17.7	16.83	15.85	15.39	15.29	15.43	15.72	16.03
Vegetables, fruit, nuts	28.31	24.04	21.63	19.15	17.91	16.39	15.51	14.79	14.14	13.59	13.17
Oilseeds	Oilseeds	15.87	12.28	9.95	8.85	8.99	9.6	10.65	11.86	13.02	14.21
Sugar cane, sugar beet	107.85	56.53	38.47	30.44	26.54	21.64	16.86	12.17	8.17	5.42	4.38
Plant-based fibres	32.84	19.55	17.29	16.22	17.22	16.94	17.04	16.49	15.05	12.89	9.85
Other crops	38.29	23.38	17.13	14.13	14.79	15.09	15.72	15.63	14.5	12.46	9.35
Cattle, sheep, goats, horses	25.34	36.22	40.02	36.7	34.28	32.38	31.36	30.63	29.87	28.99	28.15
Raw milk	20.82	57.09	66.98	55.06	48.62	43.86	40.95	38.47	35.98	33.36	30.77
Forestry	31.3	28.35	19.54	12.45	8.43	7.63	8.3	9.81	11.85	14.31	17.09
Fishing	24.76	25.83	24.7	22.57	20.48	19.05	18.38	18.59	19.49	20.76	22.22
Animal products nec	33.85	45.69	47.75	42.12	38.81	36.16	34.45	33.01	31.62	30.31	29.39
Wool, silk-worm cocoons	6588.16	61.34	32.92	27.4	30.46	28.76	29.13	28.72	27.39	25.35	21.91
Meat: cattle, sheep, goats, horse	137.92	215.19	165.75	119.88	100.74	90.2	84.05	79.7	76.12	73.1	70.9
Meat products nec	114.66	80.88	50.15	34.27	25.7	23.18	22.4	23.65	26.22	29.44	33.27

Vegetable oils and fats	64.87	115.19	124.41	104.84	94.92	87.5	82.99	79.25	75.63	71.89	68.17
Dairy products	115.88	81.66	49.02	31.23	20.58	19.22	20.04	23.29	27.76	32.75	38.92
Processed rice	171.29	104.08	80.19	69.21	64.17	57.3	50.74	44.27	38.72	34.77	32.9
Sugar	35.35	33.11	26.64	21.03	17.34	16.01	15.74	16.6	18.23	20.29	22.67
Food products nec	28.14	25.61	20.55	16.91	14.55	13.87	13.96	14.95	16.58	18.58	20.82
Beverages and tobacco products	111.21	90.22	44.85	16.34	1.47	−4.37	−6.4	−5.27	−2.08	2.33	7.74
Total output	7865.96	1227.53	964.43	749.42	649.41	588.06	556.54	539.67	529.84	523.86	522.53

Source: Authors' simulation.
Note: "nec" refers to all the possible products that can be included in a particular sector.

Table 5. Output: agricultural sectors.

	2020	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
10% scenario											
Extraction	−5.49	−6.46	−7.76	−9.1	−11.44	−12.55	−13.4	−13.68	−13.61	−13.3	−12.3
Manufacturing	−5.38	−5.82	−6.22	−6.63	−7.26	−7.44	−7.47	−7.31	−7.05	−6.73	−6.28
Services	0.53	0.79	0.97	1.17	1.57	2.03	2.68	3.42	4.21	5.04	5.84
30% scenario											
Extraction	−18.14	−32.45	−43.78	−47.27	−53.9	−57.82	−60.45	−62.56	−64.84	−66.7	−67.8
Manufacturing	−16.52	−22.51	−27.89	−32.1	−37.32	−41.39	−44.42	−45.86	−46.06	−45.5	−44.3
Services	2.43	5.03	8.44	10.67	11.24	10.96	11.03	11.7	12.85	14.2	15.67

Source: Authors' Simulation.

Table 6. Value added in agriculture and agri-based processing sectors.

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
10% scenario											
Paddy rice	16.47	12.03	8.83	6.07	4.29	1.98	0.11	−1.38	−2.33	−2.81	−2.55
Wheat	5.2	2.09	0.89	0.19	−0.57	−1.36	−2.16	−2.85	−3.34	−3.73	−3.89
Other cereal grains	−2.51	−2.72	−2.63	−2.47	−2.34	−2.29	−2.29	−2.31	−2.34	−2.38	−2.41
Vegetables, fruit, nuts	0.38	−0.66	−1.1	−1.45	−1.68	−2.13	−2.53	−2.9	−3.22	−3.46	−3.66
Oilseeds	−2.17	−3.03	−3.01	−2.77	−2.87	−2.69	−2.55	−2.29	−1.92	−1.4	−0.54
Sugar cane, sugar beet	24.92	17.15	11.64	7.46	5.33	3.14	1.91	1.23	0.94	0.94	1.06
Plant-based fibres	3.71	−0.94	−2.77	−3.81	−4.28	−4.91	−5.24	−5.37	−5.34	−5.16	−4.86
Other crops	5.29	1.64	0.12	−1	−1.77	−2.89	−3.86	−4.64	−5.2	−5.6	−5.77
Cattle, sheep, goats, horses	−1.78	−0.76	0.89	2.69	4.15	4.67	4.52	3.89	3.12	2.28	1.32
Raw milk	−3.92	−1.92	2.73	8.26	11.94	12.25	10.58	8.34	6.26	4.45	2.72
Forestry	0.4	1.27	1.63	1.59	1.28	0.73	0.15	−0.4	−0.86	−1.25	−1.58
Fishing	−1.6	−1.05	−0.66	−0.27	0.01	0.34	0.59	0.77	0.89	0.91	0.82
Animal products nec	0.83	1.61	3.4	5.19	6.44	6.32	5.57	4.51	3.48	2.55	1.6
Wool, silk-worm cocoons	1343.08	146.18	22.66	3.24	0.31	−4.07	−5.81	−6.96	−7.7	−8.3	−9.29
Meat: cattle, sheep, goats, horse	19.73	28.01	38.32	43.8	43.21	37.83	31.9	26.74	22.72	19.63	16.95
Meat products nec	22.71	21.24	20.29	19.27	17.25	16.25	15.3	14.78	14.6	14.78	15.61
Vegetable oils and fats	7.53	9.78	15.2	21.44	25.46	25.25	22.88	19.98	17.37	15.12	13
Dairy products	23.28	21.8	21.3	20.88	18.79	18.26	17.6	17.34	17.38	17.65	18.41
Processed rice	37.76	29.08	22.87	18.09	15.75	13.18	11.71	10.84	10.41	10.28	10.25
Sugar	1.78	2.28	2.82	3.36	3.44	3.64	3.67	3.74	3.89	4.13	4.62
Food products nec	−0.36	0.15	0.49	0.78	0.69	0.83	0.86	0.94	1.05	1.19	1.45
Beverages and tobacco products	19.83	22.37	23.34	22.6	20.18	17.43	14.41	11.75	9.58	7.76	6.61
30% scenario											
Paddy rice	37.93	13.4	2.42	−2.9	−3.58	−5.01	−5.79	−6.88	−8.38	−10.29	−12.73
Wheat	6	−5.79	−12.55	−17.16	−20.74	−22.41	−23.32	−23.35	−23.16	−23.46	−23.93
Other cereal grains	−7.36	−7.63	−7.96	−8.77	−9.56	−10.11	−10.38	−10.36	−10.16	−9.85	−9.47
Vegetables, fruit, nuts	−1.19	−4.41	−6.16	−7.87	−8.95	−9.91	−10.49	−10.93	−11.33	−11.63	−11.77
Oilseeds	−7.98	−10.66	−13.31	−14.86	−15.83	−15.5	−14.92	−14	−12.97	−11.97	−10.87
Sugar cane, sugar beet	59.22	20	6.39	0.63	−2.4	−5.79	−9.2	−12.54	−15.34	−17.17	−17.57
Plant-based fibres	1.58	−8.47	−9.99	−10.41	−9.8	−9.62	−9.32	−9.5	−10.37	−11.8	−13.79
Other crops	6.42	−4.9	−9.63	−11.65	−11.34	−10.86	−10.31	−10.29	−11.06	−12.54	−14.71
Cattle, sheep, goats, horses	−3.18	5.3	8.35	6.06	4.09	2.85	2.2	1.75	1.27	0.69	0.2
Raw milk	−6.7	21.33	29.09	20.2	15.14	11.74	9.64	7.88	6.09	4.21	2.41
Forestry	1.01	−1.13	−7.73	−12.9	−16.09	−16.44	−15.77	−14.46	−12.76	−10.75	−8.43
Fishing	−3.66	−2.74	−3.47	−4.88	−6.59	−7.48	−7.89	−7.63	−6.86	−5.82	−4.57
Animal products nec	2.98	12.2	13.94	9.88	7.23	5.45	4.29	3.34	2.42	1.57	1.1
Wool, silk-worm cocoons	5046.81	24.22	2.53	−1.46	0.86	−0.23	0.2	0.02	−0.88	−2.32	−4.79
Meat: cattle, sheep, goats, horse	83.09	142.7	104.88	69.93	55.15	47.35	42.82	39.67	37.12	35	33.59
Meat products nec	65.22	39.4	15.87	3.77	−2.75	−4.63	−5.2	−4.22	−2.25	0.19	3.09
Vegetable oils and fats	27.27	66.08	73.33	58.54	50.81	45.35	42.03	39.29	36.63	33.89	31.23

Dairy products	66.06	39.9	14.78	1.02	−7.02	−8.22	−7.73	−5.39	−2.11	1.5	5.93
Processed rice	108.02	56.57	38.48	30.45	26.55	21.64	16.86	12.16	8.16	5.4	4.36
Sugar	4.29	2.68	−2.17	−6.3	−9.16	−10.02	−10.14	−9.39	−8.06	−6.4	−4.47
Food products nec	−1.53	−3.39	−7.14	−9.78	−11.59	−11.97	−11.79	−10.92	−9.58	−7.94	−6.09
Beverages and tobacco products	61.96	46.05	11.48	−10.06	−21.49	−25.62	−26.91	−25.77	−23.07	−19.4	−14.9

Source: Authors' simulation.

Table 7. Value added in non-agricultural sectors.

	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
10% scenario											
Extraction	−5.49	−6.46	−7.76	−9.1	−11.44	−12.6	−13.4	−13.68	−13.61	−13.29	−12.3
Manufacturing	−5.38	−5.82	−6.22	−6.63	−7.26	−7.44	−7.47	−7.31	−7.05	−6.73	−6.28
Services	0.53	0.79	0.97	1.17	1.57	2.03	2.68	3.42	4.21	5.04	5.84
30% scenario											
Extraction	−18.14	−32.45	−43.78	−47.27	−53.9	−57.8	−60.45	−62.56	−64.84	−66.74	−67.81
Manufacturing	−16.52	−22.51	−27.89	−32.1	−37.32	−41.4	−44.42	−45.86	−46.06	−45.47	−44.25
Services	2.43	5.03	8.44	10.67	11.24	11	11.03	11.7	12.85	14.21	15.67

Source: Authors' simulation.

under scenario 2. In both policy simulation scenarios, the oilseeds industry would lose value over all time periods. In scenario 1 of policy simulation, the sugar cane sector would experience value addition, whereas in scenario 2 of policy simulation, the sugar cane sector would lose value over time. In both policy simulation scenarios, the plant-based fibres sector would only experience value addition in the first period, while other crops would experience value addition in policy simulation scenario 2.

In the majority of time periods, value would be added to livestock sectors under both policy simulation scenarios, whereas raw milk would be more valuable under policy simulation scenario 2 than under policy simulation scenario 1. In scenario 2 of policy simulation, the forestry and fishing industries would lose more value than in scenario 1 of policy simulation. The agro-based processing sectors would experience greater added value in scenario 1 of the policy simulation than in scenario 2 of the policy simulation, but would incur losses in certain years.

Table 7 then demonstrates that the extraction and manufacturing sectors would experience value losses under both policy simulation scenarios, with the second policy simulation scenario resulting in enormous losses. However, the services sector would gain more value in scenario 2 than scenario 1 and would never lose value.

6. Conclusions

The purpose of technology transfer is to enhance national productivity and economic growth. Despite receiving assistance in the form of agricultural technical assistance, Zimbabwe's agricultural sector continues to experience difficulties. Consequently, this study proposed scenarios to assess the potential level of technology the economy may require. According to the results, Zimbabwe's economy would improve if more certified seeds, high-quality fertilisers, and agricultural machinery were transferred and adopted in the agricultural sector. All of the indicators indicated that a 30% increase in the use of certified seeds, high-quality fertilisers, and agricultural machinery (policy simulation scenario 2) would be more beneficial to the economy than a 10% increase (policy simulation scenario 1). Variables such as the trade balance, however, indicated that the nation would experience periods of trade surpluses and deficits. Even if the economy benefited more in certain aspects under policy simulation scenario 2, the CPI indicated that the cost of living and inflation rate would increase at rates that the Zimbabwean economy cannot currently afford. The industrial output of the sectors would be positively impacted by any level of technology transfer, but especially in scenario 2 of the policy simulation, with the exception of the wheat, beverage, and tobacco industries, which would experience decreases during certain time periods. All policy scenarios would have a negative impact on the extraction and manufacturing sectors, but scenario 2 would have the greatest impact. However, the services sector would improve more in scenario 1 of policy simulation than in scenario 2 of policy simulation. In terms of value-added, the industrial, extraction, and manufacturing sectors would benefit more from policy simulation scenario 1 than scenario 2. Only the services sector would gain more value under scenario 2 of policy simulations. The study concludes that Zimbabwe's agricultural sector requires a greater transfer of agricultural technology in the form of machinery, certified seeds, and high-quality fertilisers. A moderate increase would balance out the economic losses and gains. To address the issue of low productivity in Africa, developing nations generally commit to devising strategies that close the technological gap by removing physical, economic, and social barriers to technological adoption.

7. Recommendations

The study suggests a four-component strategy for economic development and poverty reduction in Zimbabwe via technology diffusion and adoption: i) capacity-building for technology transfer, (ii) rural infrastructure development, (iii) rural microfinance, and (iv) duty-free agricultural machinery. Building capacity is essential for technology transfer. Adopting and adapting transferred technology necessitates policies aimed at building the capacity of smallholder farmers by intensifying agricultural technology and information technology training programmes. Establishing vocational training centres in rural areas that offer these courses to farmers at subsidised rates would increase their knowledge and proficiency in the use of new technologies. Similarly, rural infrastructure development initiatives are indispensable for technology diffusion. As a means of transferring technology, rural infrastructure such as roads and communication networks play a crucial role in ensuring access to farm inputs such as high-quality fertilisers and certified seeds. Establishing microfinance institutions in rural areas is essential for Zimbabwe to maximise its technology transfer benefits. Access to high-quality fertilisers, certified seeds, machinery, and other forms of technology has become dependent on rural finance. A policy-based lending tool is crucial. Lastly, policies that encourage the duty-free importation of agricultural capital equipment are of the utmost importance. Such policies would reduce the price of such machinery, making it affordable for smallholder farmers, and would also increase the number of smallholder farmers who have access to the equipment. It would be preferable to involve all farmers or producers as active decision-makers regarding the type of technology they may require, particularly the type of agricultural machinery, rather than adopting all available technology, which may not produce the desired results.

Disclosure statement

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