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Modelling the Economy-Wide Impact of Technological Innovation and Mapping Agricultural Potential: The case of Malawi

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Acronyms

AEZ	Agro-Ecological Zones
CGE	Computable General Equilibrium
EV	Equivalent Variation
FAO	Food and Agriculture Organization
FISP	Farm Input Subsidy Program
GDP	Gross domestic product
GFCF	Gross Fixed Capital Formation
HIV	Human Immunodeficiency Viruses
IIASA	International Institute for Applied Systems Analysis
SAM	Social Accounting Matrix
SSA	Sub-Saharan Africa
WDI	World Development Indicators

Abstract

This discussion paper analyzes the economy-wide impact of a series of agricultural innovations in Malawi. Using an agricultural focused computable general equilibrium model disaggregated to reflect Malawi agro-ecological zones, we simulate three scenarios: one involving smallholders catching up to the production frontier, and two scenarios of agronomic innovations consisting in changes in level and application rate of nitrogen. Our results show a positive impact on the economy following an increase in maize yield and production efficiency under the different scenarios.

Keywords: agricultural innovation; productivity growth; CGE modeling

JEL codes: C68; Q16; Q18

1 Introduction

Malawi, a landlocked country located in the southern part of Africa, is home to Sub-Saharan Africa's (SSA) third largest lake which occupies a third of the country. Malawi has experienced slow growth over the last decade due to a number of economic, political, and climate related shocks (IMF, 2017) and is classified as one of the poorest countries with a largely rural-based population of 17 million inhabitants. In terms of social and economic development, the country falls below the average for some of the indicators in SSA.[1] For example, while the average prevalence of HIV for population ages 15 – 49 was 4.76% in SSA from 2009 to 2013, it was 11.30% in Malawi. Likewise, while the average net enrolment rate for secondary schools was 32.33% in SSA, it was 28.86% in Malawi. However, the average GDP growth rate for Malawi was higher compared to the average for SSA during the same period (5.40% and 4.01%, respectively).

Although there have been improvements for some of the socio-economic indicators, including health, education, child mortality, child nutrition and other non-monetary poverty measures, monetary poverty remains a major challenge in the country. In 2010, using a basic needs basket of 37,000 Kwacha, national poverty stood at 50% while rural poverty was estimated at 57%.[2] Overall poverty, using the international poverty line of $1.90 per day (using 2011 international prices), was estimated at 71% (IMF, 2017). Being a rurally based economy, the country is largely dependent on the agricultural sector, which contributes a third of the total GDP. It is estimated that of the 3.4 million ultra-poor in Malawi, 96% depend on maize and tobacco farming (World Bank, 2013). As such, like in many other countries in Sub-Saharan Africa, the agricultural sector remains one of the most important sectors for promoting economic growth and poverty reduction in Malawi.

Over the years, maize farming has been the dominant activity for smallholder agriculture in Malawi (Tchale, 2009; FAO, 2016) and is an important source of livelihood for a large share of the population most of whom live in poverty. Crop production in Malawi is mainly rain-fed and is therefore prone to inconsistent yields due to climate related shocks, including drought and flooding. Agriculture and climate change management have been identified among the key priority areas that the government needs to focus on to promote economic development and reduce poverty. Given important resource constraints, the role that technological innovation can play in enhancing agricultural productivity is increasingly recognized.

This study uses a disaggregated agricultural focused Computable General Equilibrium (CGE) model to assess the effects of technological innovations in the maize sector in Malawi. Three scenarios are considered: smallholders catching up to the production frontier, and two scenarios of agronomic innovations involving changes in level and application rate of

[1] World Development Indicators (WDI), 2017
[2] 76.3 Kwacha = 1 USD (2011 PPP)

nitrogen. Results from the analysis show that there is a positive impact on the economy following an increase in maize production due to yield and efficiency increases under the different scenarios. Technological innovations have a high agricultural potential in Malawi as maize production moves towards the production frontier. The rest of the report is organised as follows. Section 2 gives a brief overview of maize production in Malawi while Section 3 provides the methodology used for the study. The results are presented in Section 4 with a conclusion in Section 5.

2 Maize in Malawi

2.1 Production

The agricultural sector in Malawi is dominated by maize production, usually by smallholder farmers (Tchale, 2009). It is estimated that 92% of the country's agricultural land is used for maize production, cultivated by up to 97% of farmers and contributing over 54% of national caloric intake (Msowoya and Madani, 2016). A contributing factor to the popularity of maize production in the country is the favourable sub-tropical climate characterised by three seasons. A survey of various reports shows that the government, through various stakeholders, directly targets the maize sub-sector for example through the provision of input subsidies to boost production. The sector is also targeted by income support through national purchase of maize to boost livelihoods (World Bank, 2013; FAO, 2015). The result has been an increase in maize production accompanied by increasing yields. Figure 1 below shows the recent trends in maize production.

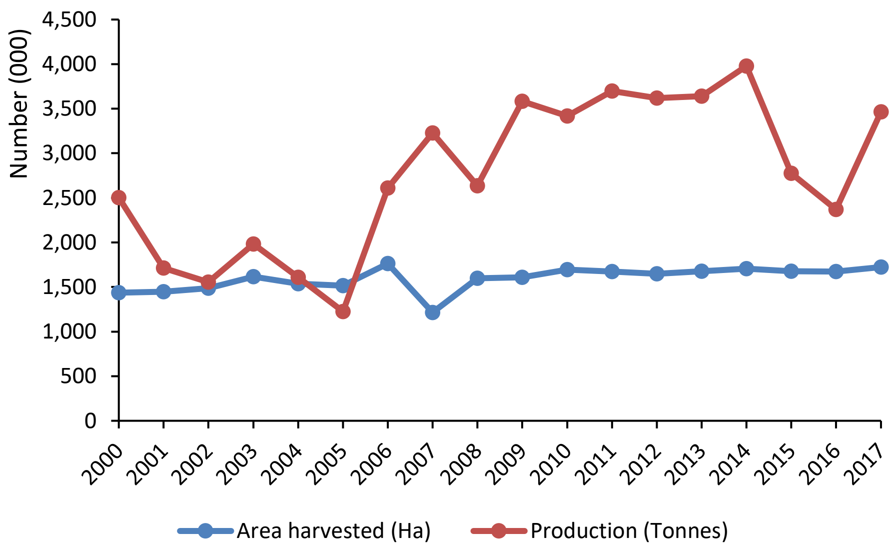

Figure 1: Recent trends in maize production in Malawi

Source: FAO (2019)

While the area harvested (hectares) remained almost constant from 2008 to 2016, production increased over the same period but has declined since 2014. The increase in production is largely accounted for by the sharp increase in yields between 2005 and 2007 from 0.8t/ha to 2.7t/ha as shown in Figure 2, as opposed to an increase in the area under cultivation. As shown in Figure 1, the area under cultivation increased by an average of 0.6% between 2009 and 2016. It is reported that the fertilizer subsidy program implemented in Malawi in 2005/06 (under the Farm Input Subsidy Program (FISP)) was very successful, enabling households to purchase fertilizer, hybrid seeds and/or pesticides at highly subsidized prices (Chauvin, Mulangu and Porto, 2012). This can partly explain the sharp increase in yields. However, even though the high yields were above the pre-FISP programme, there has been fluctuations in yield over time. For example, Figure 2 shows a decline in yield from 2.6 t/ha in 2007 to 1.6 t/ha in 2008. The drop in yield in 2008 was partly attributed to poor rainfall (Schiesari, Mockshell and Zeller, 2016). Between 2009 and 2014, yield averaged 2.2 t/ha but dropped by 14.5% from 2015 to 2016. The drop in maize production has again partly been attributed to occasional droughts in some parts of the country and flooding in others especially in the northern region. This was reversed in 2017 and we see an increase in both production and yield. Overall, there was an increase in productivity after the introduction of the FISP compared to the period before the programme. After 10 years of the implementation of the programme, there were calls to reform the FISP programme in 2016/17 largely bordering on changes to the targeting of beneficiary farmers, increased involvement of the private sector in the distribution of inputs and direct retailing and a pilot program to target low productivity farmers in Dowa and Rumphi districts (DFID, 2017). Results of the above reforms show that there were differences in the yields of the targeted farmers and other beneficiaries, with the former reporting higher yields.

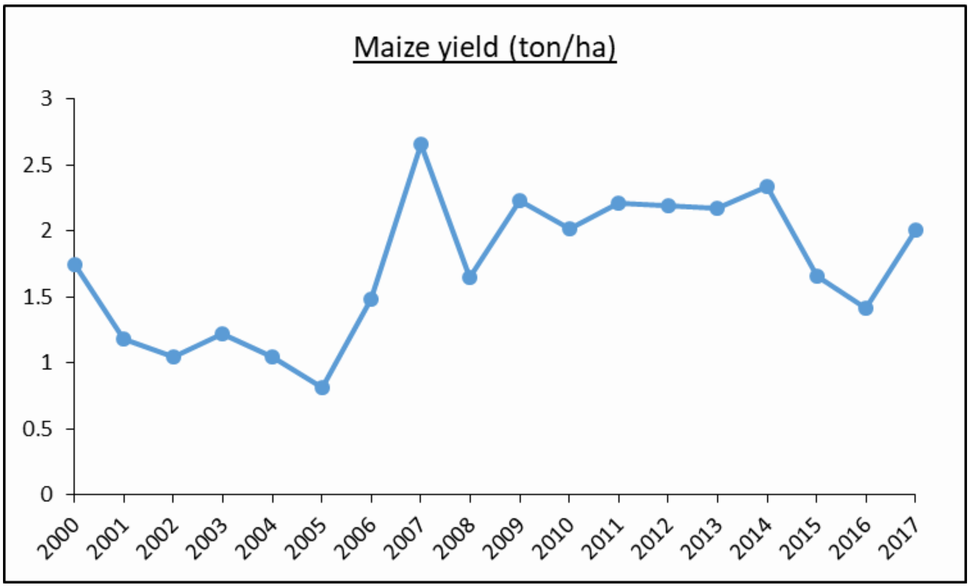

Figure 2: Maize yields

Source: FAO (2019)

With a reversal of the declining trends in production in 2017, there is need for continued improvement in seed and fertilizer quality, education on the use of modern farm technologies and monitoring of soil nutrients as more fertilizer is used on the farms. This will provide up to date information on the input use and productivity. These options remain the most feasible given the land pressures imposed by increasing population, making it difficult to increase the area under production. As noted in Heisey and Smale (1995) in 1995, Malawi was already characterised as a country that had "already arrived at its national land constraint".

2.2 Public spending in agriculture

The agricultural sector takes up a large share of total spending given the fact that the sector also dominates in its contribution to GDP. A public expenditure review in Malawi by the World Bank showed that the share of total expenditures going to the agricultural sector averaged 19% between 2007/2008 and 2011/2012 (World Bank, 2013). Data obtained from the ReSAKSS website shows that the average share of total expenditure going to the agriculture sector from 2010 to 2015 was 16%.[3] Given that maize production dominates the agricultural sector, it is expected that of the 16% share of total expenditure going to the agricultural sector, maize constitutes a large share. Indeed, maize is reported to be among the main commodities that are important for food security in Malawi.[4] As a result, the bulk of expenditure in agriculture specific expenditure was in support of maize production and productivity through the FISP (FAO, 2015).

The report also shows that between 2003 – 2006, 50% of all public expenditure in support of food and agriculture was dedicated to maize production through provision of variable input subsidies. Likewise, 69% of agriculture specific spending was accounted for by the maize sub-sector over the same period. This spending pattern further heightens the importance given to the maize sector in promoting growth and supporting livelihoods.

[3] www.resakks.org

[4] The other crop is cassava

3 Methodology

This study makes use of a CGE model to evaluate the economy-wide impact of technological innovation in agriculture on the Malawian economy. Starting from a standard CGE model (Lofgren et al, 2002d, 2002; Decaluwe et al, 2012), the model assumes perfect competition in its formulation. The standard CGE model is then used to build an agriculture focused CGE model for Malawi that is recursive dynamic. The standard CGE model does not account for regional disaggregation. However, for this study, it was necessary to account for spatial heterogeneity and different conditions across agro-ecological zones (AEZs). Using AEZ mapping discussed below, the land factor in the CGE model was split by zone as well as fertilizer application. This allowed us to model an extended value-added specification for the production process.

3.1 Regional disaggregation

Disaggregated data obtained from the Malawi eAtlas was used for the regional mapping.[5] The 27 districts in Malawi were divided into four AEZs as shown in the map below, with Table 1 showing the districts in each AEZ.[6] The purpose of zoning is to classify regions with similar potential and constraints together. FAO identifies different zones based on combinations of soils, landform and climatic characteristics. [7] As will become clear later, different regions are suitable for different crops in Malawi and therefore the land area dedicated to each crop differs by region. The grouping of districts into homogenous AEZs was done using Length of Growing Periods from the FAO/IIASA Global Agro-Ecological Zoning dataset.

Table 1: Mapping of districts into AEZs8

AEZ 2	AEZ 3	AEZ 4
Chiradzulu, Chipita, Karonga, Mzimba, Nkhotakhota, Nsanje, Thyolo, Zomba	Balaka, Blantyre, Chikwawa, Dedza, dowa, Kasungu, Lilongwe, Machinga, Mangochi, Mchinji, Mwanza, Neno, Ntcheu, Ntchisi, Salima	Mulanje, Nkhata Bay, Phalombe, Rumphi

[5] http://eatlas.resakss.org/Malawi/en/

[6] One district, Likoma, for which the production area and total yields are very small was not categorised in any of the three major AEZs for purposes of analysis.

[7] Landform refers to geographic features that naturally exist on the earth's surface e.g. hills, oceans, mountains etc.

[8] AEZ 1, which represents Likoma was not included in the analysis because of the small size and share of production which was very marginal.

Using the land factor in the CGE model as the entry point, regional returns to land were obtained as proportions of the shares in total production from the AEZs

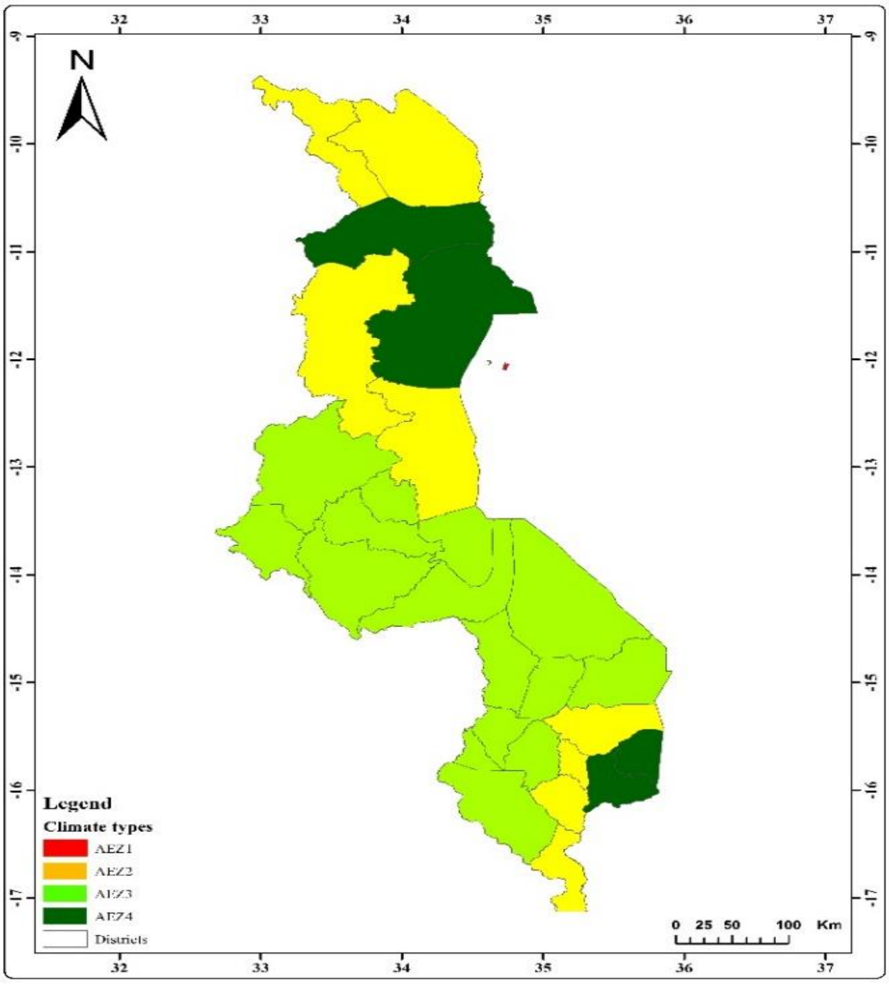

Figure 3: Agro-ecological zoning in Malawi

Source: Rezaei and Gaiser (2018); Notes: AEZ1 (small island, Likoma) LGP 30-59, AEZ2 LGP 150-179, AEZ3 LGP 210-239, AEZ4 LGP 210-239

3.2 Cultivated area and production by AEZ

The shares of total production used to generate regional returns to land are shown in Table 2 below while the share of cultivated land dedicated to each crop is shown in Table 3. As shown in Table 2, AEZ 3 takes up the largest share of cultivated land and has the largest share of production. Maize takes up the largest share of cultivated land in all AEZs with the largest share of land dedicated to maize production in AEZ 3. This is not surprising given the prominent position that maize holds in most SSA countries.

Table 2: Share of total cultivated area and production (2016)

AEZ	Share of total cultivated area (Ha)	Share of total production (Ha)
AEZ 2	25%	22%
AEZ 3	64%	66%
AEZ 4	11%	12%
Total	**100%**	**100%**

Table 3: Share[9] of cultivated land in AEZ dedicated to each crop in 2016

AEZ	Maize	Rice	Groundnut	Tobacco	Pulse	Cassava	Total
AEZ 2	47%	3%	8%	3%	26%	12%	**100%**
AEZ 3	53%	1%	13%	4%	25%	4%	**100%**
AEZ 4	41%	4%	6%	3%	33%	14%	**100%**

3.3 Extended production technology

To capture technological innovations in agriculture, the model was customised to accommodate land and fertilizer use in each AEZ, which was then aggregated to a composite factor of production. Production is therefore extended from the standard production technology to incorporate disaggregated land and fertilizer use. Figure 4 below provides a schematic flow of the production technology, incorporating both land and fertilizer use by each AEZ (region in the figure).

[9] It is possible that there were other crops planted in the AEZs for which data was not available. As a result, these ratios are based on the mentioned crops only

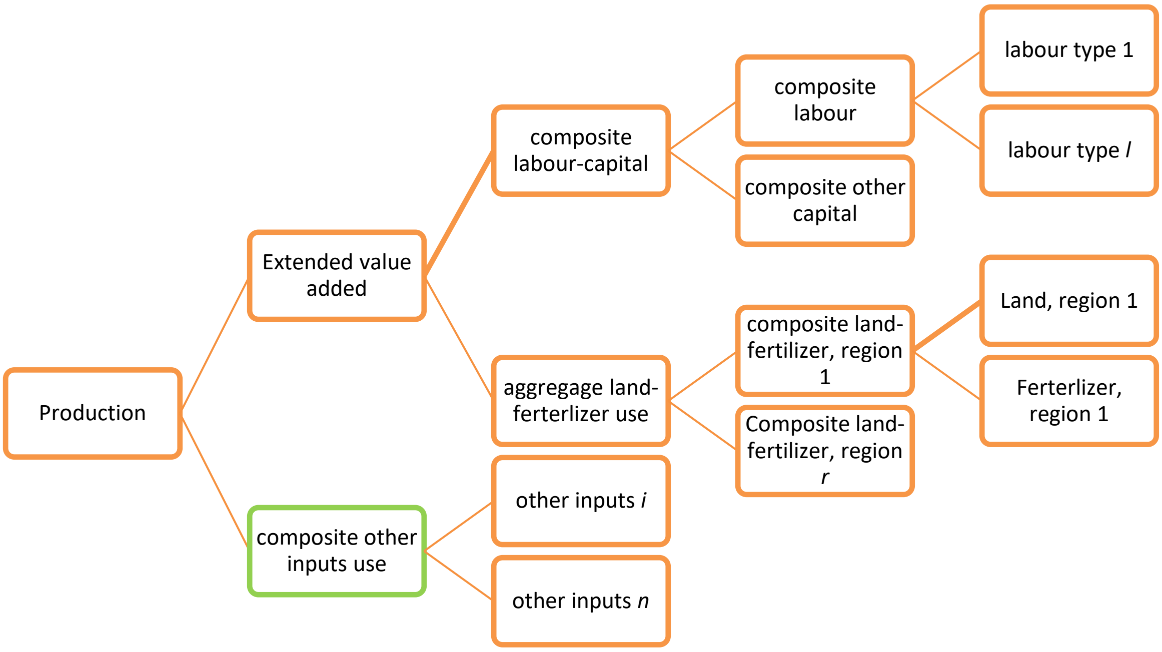

Figure 4: Extended production technology

3.4 Distribution of factors and incomes across AEZs

Tables 4 and 5 below show the distribution of factor income and household income across the AEZs and the source of factor income by crops across the AEZs. The data was extracted from the updated 2007 Social Accounting Matrix for Malawi. The table shows that AEZ 3 generates a larger proportion of factor incomes both from land and fertilizer use. It also follows that households located in AEZ 3 earn more income from the two factors compared to households in AEZ 2 and 4. Households in AEZ 4 earn the least from factors.

Comparing rural and urban households, the table shows that rural households earn more than urban households. This is not surprising as Malawi is dominated by smallholder farmers mainly located in the rural areas. From Table 4, it is evident that most of the factor income for AEZ 3 is generated from maize and non-foods (see footnote for the composition of non-food). It is therefore safe to conclude that maize alone generates more income for households in AEZ 3 compared to other individual crops. Other foods however generate most of the income for AEZ 2 and 4.

Table 4: Distribution of factor income across AEZs

	Total	AEZ 2	AEZ 3	AEZ 4
Factor incomes				
Land use	59,885.75	17,143.57	34,069.21	8,672.97
Fertilizer use	26,433.41	6,283.55	17,309.19	2,840.67
Distribution of factor income from land to households (quintiles)				
Rural Q1	3,134.33	897.27	1,783.13	453.93
Rural Q2	10,705.96	3,064.81	6,090.66	1,550.49
Rural Q3	5,542.06	1,586.53	3,152.90	802.63
Rural Q4	10,321.95	2,954.88	5,872.19	1,494.88
Rural Q5	24,280.15	6,950.71	13,813.06	3,516.38
Urban Q1	48.40	13.86	27.54	7.01
Urban Q2	98.54	28.21	56.06	14.27
Urban Q3	184.05	52.69	104.71	26.66
Urban Q4	623.88	178.60	354.93	90.35
Urban Q5	4,946.43	1,416.02	2,814.04	716.37

Source: Malawi 2007 SAM

Table 5: Distribution of factor incomes by crops[10] and AEZs

	Maize	Other foods	Non-food	Other crops	Total
Land: AEZ 2	3,864.07	8,589.67	3,731.15	958.67	17,143.57
Land: AEZ 3	11,436.31	6,329.94	11,870.58	4,432.38	34,069.21
Land: AEZ 4	1,417.73	5,024.99	1,928.82	301.43	8,672.97
Fertilizer use: AEZ 2	2,903.14	937.95	2,265.57	176.89	6,283.55
Fertilizer use: AEZ 3	8,592.29	691.20	7,207.88	817.83	17,309.19
Fertilizer use: AEZ 4	1,065.16	548.70	1,171.19	55.62	2,840.67

Source: Malawi 2007 SAM

3.5 Data

The social accounting matrix is the main data source that has been used for this analysis. Specifically, the data used in the CGE model was obtained from the Malawi 2007 Social Accounting Matrix (SAM) developed by IFPRI (Douillet, Pauw and Thurlow, 2008). The social accounting matrix records receipts and payments in a country for a given year. It is thus considered a good representation of the economic activities in a country, providing a

[10] Food includes rice, other cereals, cassava, roots and pulses while non-food includes tobacco, cotton and horticulture

snapshot of the economic structure of the country in that period. The SAM consists of 37 activities (14 related to agriculture, 12 industries and 11 services). There are three types of the labour factor, differentiated by education level (with primary education or less, with secondary education or less and with tertiary education or less) and two types of the capital factor, land, and other capital. In addition, there are sixteen institutions classified as 10 household types, three tax accounts, one government, one corporate account and rest of the world account. Households are further subdivided into rural households (five quintiles) and urban households (five quintiles). The capital accounts consist of Gross Fixed Capital Formation (GFCF) and change in inventories. Finally, there is an account that records the trade and transport margins.

The 2007 SAM was updated to reflect the most recent structure of the economy. To achieve this, new data obtained from the World Bank's World Development Indicators (WDI) was introduced into the already balanced 2007 SAM, and the cross entropy optimisation criteria were used to rebalance the new SAM (see Fofana, Lemelin and Cockburn, 2013). The most recent data available was up to 2014 and hence 2014 was used as the target year. Table 6 below shows the old structure represented in the 2007 SAM and the 2014 structure represented by data obtained from the WDI. Only a selected number of variables were used to update the SAM as shown in Table 6 below.

Table 6: Data showing the structure of the economy

Indicator variable	2007 SAM	2014 WDI data
Investment/GDP	33.0%	15.4%
Government consumption/GDP	13.5%	17.4%
Exports/GDP	34.4%	45.8%
Imports/GDP	60.0%	56.1%
Agriculture value added/GDP	36.5%	33.3%
Industry value added/GDP	7.9%	17.0%
Manufacturing value added/GDP	15.5%	11.4%

Source: The SAM data was obtained from IFPRI while WDI data was obtained from the World Bank

4 Scenario Implementation

The economy-wide impacts of agricultural innovation are modelled on three innovation scenarios: smallholders catching up with the production frontier, changes in the level and application rate of nitrogen.

4.1 Typology scenario

This scenario is based on evaluating the technological frontier in terms of production by comparing the actual production efficiency with the potential efficiency level. The objective is to estimate the growth rate in productivity needed to catch up with the production frontier. Maruyama et al. (2018) constructed agricultural typologies of micro regions in Malawi to identify micro-regional level opportunities, bottlenecks and investment gaps based on the concept of the production possibilities frontier applied to farm activities, drawing on highly detailed household-level survey and geospatial data on agro ecological conditions, accessibility and poverty.[11] This typology scenario considers that all farmers move from their current level of efficiency and the annual productivity growth rate by AEZ required to catch up with the frontier is calculated. The CGE implementation consists of increasing the baseline composite land-fertilizer scale parameter by AEZ and agricultural activity. In the analysis, we consider a 10-year timeframe to catch up with the frontier (2015-2024).

Table 7 below shows the current production efficiency levels and the annual average productivity growth needed to catch up with the production frontier over 10 years.[12] The baseline represents current production efficiency. For example, at a baseline of 59%, both AEZ 3 and 4 need to increase their efficiencies by 41% to achieve full efficiency while AEZ 2 with a 55% efficiency level, requires 45% to catch up with the production frontier. This is an increase of 69% and 82%, respectively. To catch up with the production technology frontier during the 10-year period, AEZ 3 and 4 would need to increase their efficiencies by an annual average of 5%, while AEZ 2 requires an annual average growth rate of 6%.

Table 7: Production efficiency for the typology scenario

AEZ	Baseline productivity	Annual average productivity growth (10 years)
AEZ 2	55%	6%
AEZ 3	59%	5%
AEZ 4	59%	5%

Source: Maruyama et al. (2018)

[11] See also http://eatlas.resakss.org/Malawi/en/

[12] Represents full efficiency corresponding to 1

Implementing the typology analysis in the CGE model entailed increasing the baseline productivity by AEZ and agricultural activity.

4.2 Crop scenarios

Under the crop scenarios, agricultural innovations are introduced in each AEZ coupled with changes in agricultural management practices. The scenarios presented below were obtained from Rezaei and Gaiser (2018) and implemented in the CGE model. The scenarios entail changes in nitrogen application (fertilizer use) and in yields whereby, in each scenario, the rate of nitrogen application is combined with different sowing dates and introduction of new cultivars. At the baseline, the status quo is maintained in terms of cultivars and management practices. This means that nitrogen application is maintained at 22kg/ha. In the first scenario, new cultivars (20% increase in grain filling rate and in radiation use efficiency) were introduced, current sowing dates were maintained, and nitrogen application was kept at 22 kg /ha but applied once during sowing. In the second scenario, new cultivars were introduced together with new sowing dates (25 days earlier than current sowing) and nitrogen application increased to 60 kg /ha (applied twice: at sowing and anthesis).

Rezaei and Gaiser (2018) proposed several innovations in maize production. To model these technologies, 30 years (1980-2010) of climate data were used as well as soil and management information obtained from global datasets at 0.5° x 0.5° spatial resolution. The crop modelling framework SIMPLACE was used to test the effects of innovation packages at the country level. Table 6 below shows the amount of nitrogen application in each scenario while Table 9 shows the average yield in each scenario including the baseline as well as the average growth in yields over a 10-year period. Crop scenario 2 records the highest changes in yields in all the AEZ with the highest average growth in yields over the 10-year period compared to crop scenario 2. The average yields recorded are higher in the two scenarios compared to the baseline.

Table 8: Fertilizer use (kg/ha) under the crop scenario

AEZ	Baseline (kg/ha)	Crop scenario 1 (kg/ha)	Crop scenario 2 (kg/ha)
AEZ 2	22	22	60
AEZ 3	22	22	60
AEZ 4	22	22	60

Source: Rezaei and Gaiser (2018)

Table 9: Simulated Changes in yields under the crop scenario

AEZ	Average yield (T/Ha)			Change in yield wrt baseline (T/Ha)		Annual average growth in yields over 10 years	
	Baseline	Crop Scenario 1	Crop Scenario 2	Crop Scenario 1	Crop Scenario 2	Crop Scenario 1	Crop Scenario 2
AEZ 2	2.79	3.22	4.45	1.16	1.60	1.5%	4.8%
AEZ 3	2.69	3.09	4.34	1.15	1.61	1.4%	4.9%
AEZ 4	2.7	3.12	4.11	1.16	1.52	1.5%	4.3%

Source: Rezaei and Gaiser (2018)

In the CGE implementation, changes in fertilizer use as well as changes in the average yields across all the scenarios were factored in.

5 Results

This section presents the economy-wide impact of the proposed technological innovation in the maize sector as described above. Improving the efficiency as well as the technology of production in the agriculture sector has the potential to positively impact on the growth rate of GDP. This is because the agriculture sector in Malawi is the largest contributor to the growth rate in GDP. We thus compare the growth rate in GDP over a 10-year period (2015-2024) under the different scenarios aimed at improving both the efficiency of maize production and technological innovations. While maize is the crop of focus, we also consider sectors for which there is a strong linkage with maize production. This includes sectors that use maize as an intermediate input for production (livestock, other crops and light manufacturing mainly food processing) as well as sectors that supply commodities as intermediate inputs to the maize sector (trade services and other crops).

The overall impact on GDP growth rate is shown in Figure 5 below. The results presented in Figure 5 shows that in the initial year (2015), GDP growth rate is higher than in subsequent years, and this is seen across all the scenarios. For example, at the baseline, there is a slight decline in GDP growth rate from 4.1% in 2015 to 3.8% by the year 2024. The initial increase in 2015 can be explained by the immediate impact of the agricultural innovations and changes in management practices on the economy. However, agriculture is not the only driver of economic growth and as we show in Figure 6 below, despite the continued increase in the agricultural growth rate under the typology and crop scenario 2, the GDP growth rate does not follow the same upward trend. It could be that as the agriculture sector grows, growth rates of the other sectors of the economy decline by more than the growth in the agriculture sector resulting in a net decline in GDP growth rate.

From Figure 6, we also see that the typology and crop scenario 2 result in much higher GDP growth rates compared to crop scenario 1. Arguably, crop scenario 1 only entails introduction of new cultivars while crop scenario 2 includes an increase in the rate of application of nitrogen. However, despite the decline in the GDP growth rate in all scenarios after the initial year, GDP grows at a higher rate under typology (average of 4.6%) and crop scenarios (average of 4.1 and 4.5% in crop scenario 1 and 2 respectively) compared to the baseline (average 4.0%). The typology scenario registered the highest GDP growth rate, followed by crop scenario 2.

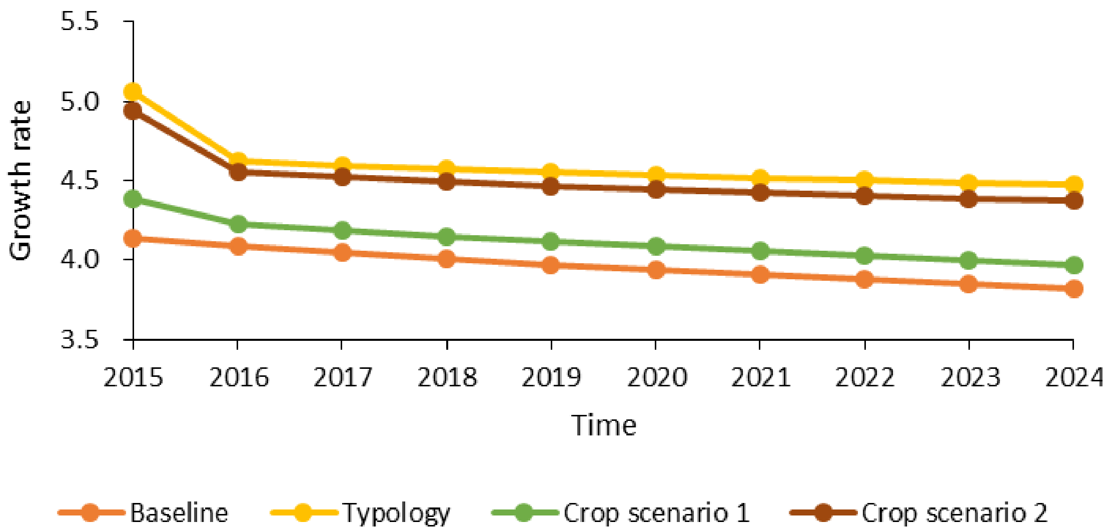

Figure 5: GDP growth rate (%)

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

From Figure 6 below, agriculture value added declines both in the baseline scenario and crop scenario 1 from 4% to 3.7% and from 4.5% to 4.1%, respectively, by 2024. These results mimic the decline in the GDP growth rate. Under the typology and crop scenario 2, the decline is only observed between the first and the second periods after which growth in agriculture value added proceeds with an upward trend. For example, under the typology scenario, the value-added declines from 5.7 to 5.2% between the first two periods but increases to from 5.2% in period 2 to 5.6% by 2024. Likewise, under crop scenario 2, agriculture value added declines from 5.5 to 5.0 % during the first 2 periods but eventually increases to 5.3% by 2024. Hence, unlike the GDP growth rate, which declines over time in all scenarios, the agricultural growth rate follows an upward trajectory under typology and crop scenario 2.

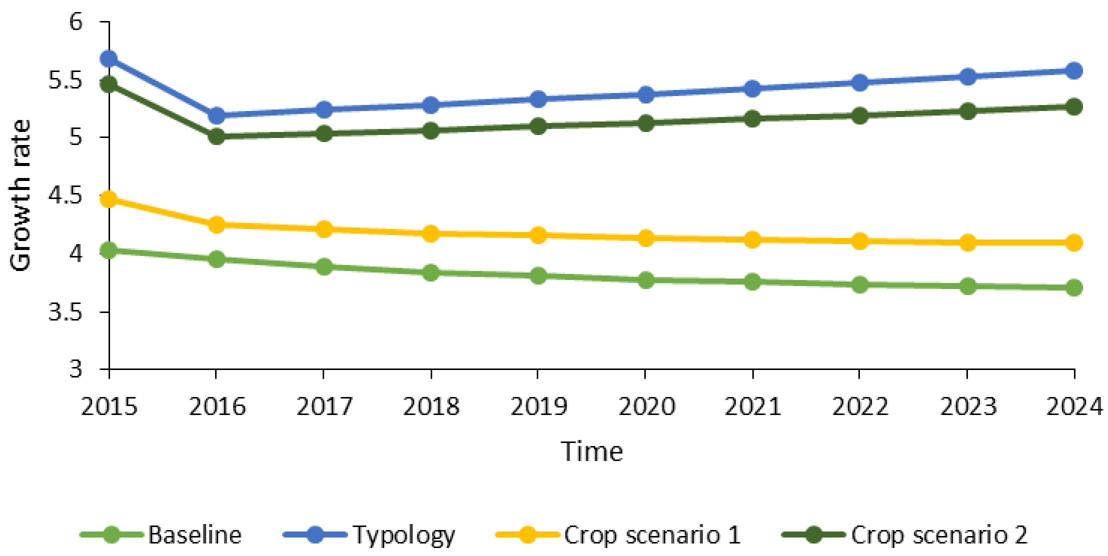

Figure 6: Agricultural growth rate (%)

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

The agriculture trade balance constitutes all sectors that make up the agriculture sector in the SAM, including maize, food crops, other crops, livestock, forestry and fishing. We expect that the change in the trade balance will largely be driven by changes in the maize sector as this is the sector where the innovations would take place. However, as mentioned above, the magnitude of the impact is bound to be compounded by the forward and backward linkages of the maize sector with other agricultural and service sectors. Figure 7 below presents the results of the change in the agriculture trade balance following technological innovations. From the Figure, we see a significant increase in the agriculture trade balance from the typology and crop scenario 2 where the trade balance increases by, respectively, 21 and 17.6% by 2024. Under crop scenario 1 the increase is only 4.4%.

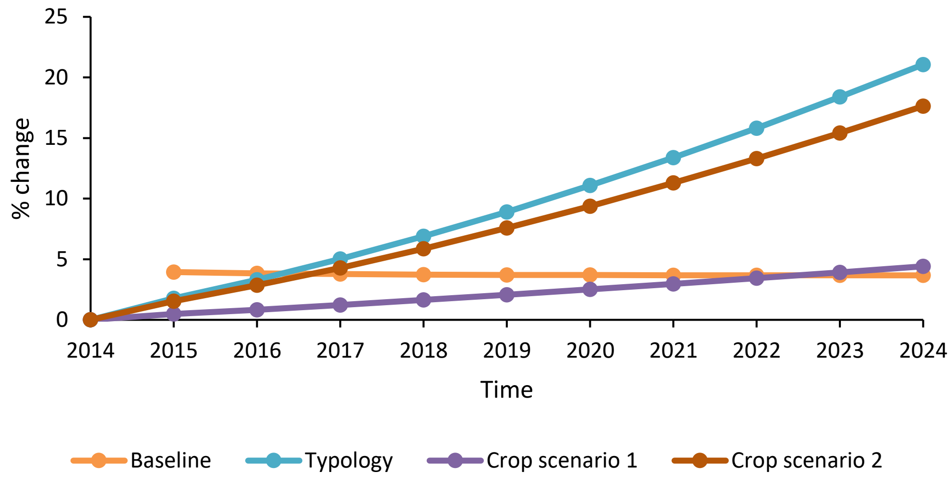

Figure 7: Percentage change in agricultural trade balance

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

As shown in Figure 8a, there is a significant increase in maize production especially under typology and crop scenario 2. For example, production increases by 66% by 2024 under the typology scenario. Under crop scenario 1, the increase in maize production is more modest compared to crop scenario 2. From the Figure we see that maize production is expected to increase to 14% by 2024 under crop scenario 1 compared to 56% under crop scenario 2. This increase in maize production is expected given the increases in projected yields and efficiency.

As noted earlier, the livestock sector, other crops and light manufacturing use maize as an intermediate input for their production.[13] At the same time, other crops and trade services are used as intermediate inputs in maize production. Hence, we expect that there will be effects in these sectors as well. As Figures 8c and 8e show, despite the increase in maize production, we see a decline in production of other crops as well as a decline in production of other food crops.[14] This could be interpreted to imply that programs that target the maize sector alone can generate adverse production effects for other crops. However, the decline in the production of food and other crops is very marginal (less than 1%) compared to the increase in maize production (reaching up to 70% under the typology scenario). This therefore justifies targeting the maize sector given the prominent position it occupies in the agricultural sector in Malawi. Livestock production also increases but by a smaller margin compared to the increase in maize production. This is expected as maize is an input for livestock production and it follows that an increase in maize production will be accompanied by an increase in

[13] Light manufacturing – comprising mainly of food processing.

[14] Food includes rice, cereals, cassava, roots, pulses

livestock production due to the fall in maize prices making it more affordable as feed for livestock.

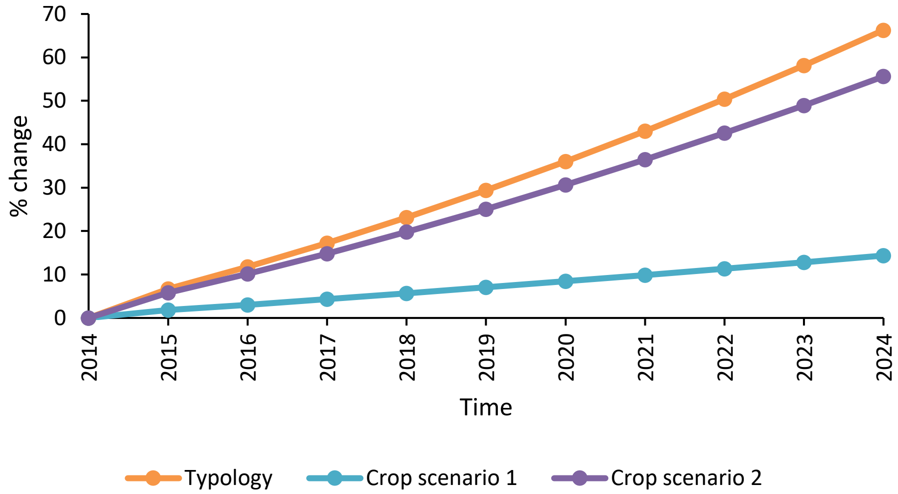

Figure 8a: Percentage change in maize production

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

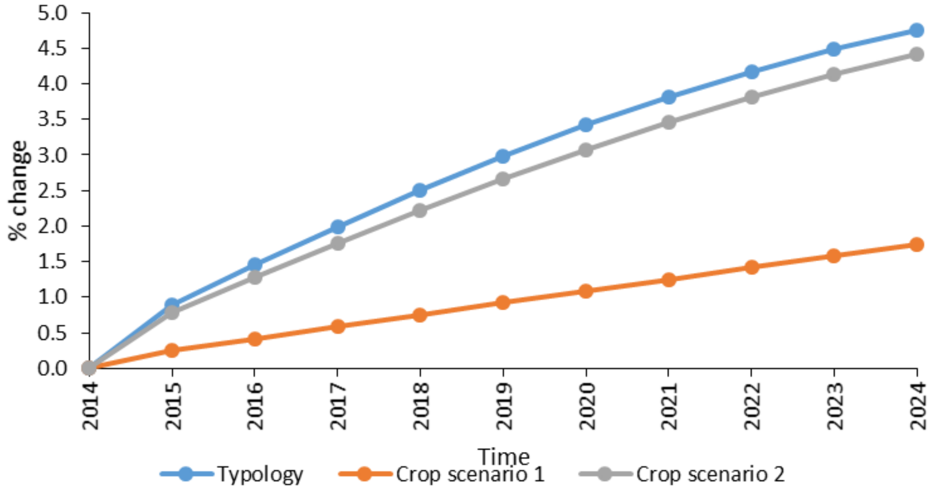

Figure 8b: Percentage change in production of light manufacturing

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

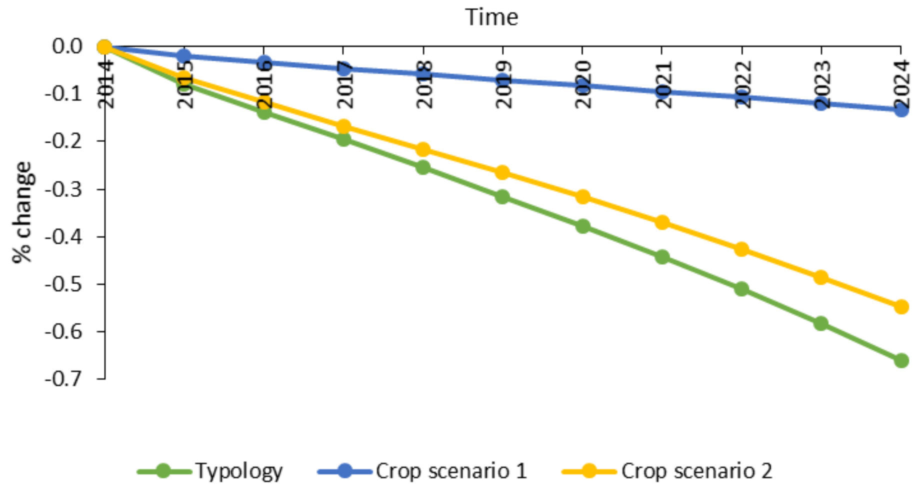

Figure 8c: Percentage change in the production of food crops

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

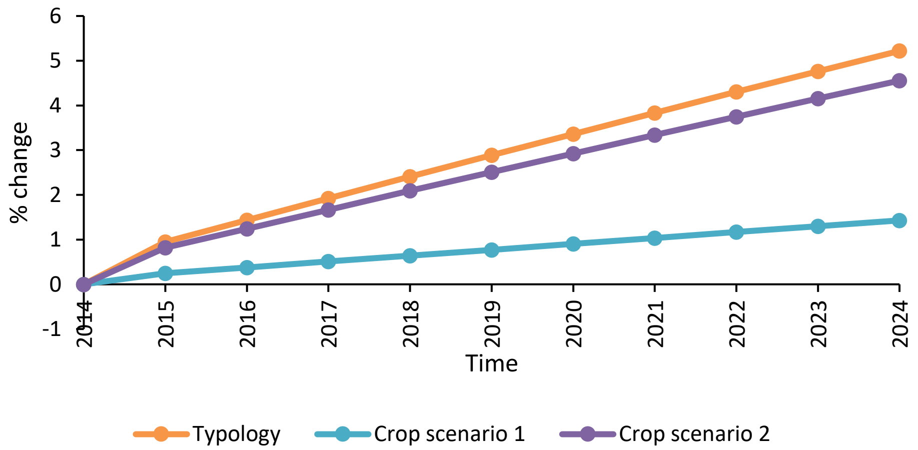

Figure 8d: Percentage change in livestock production

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

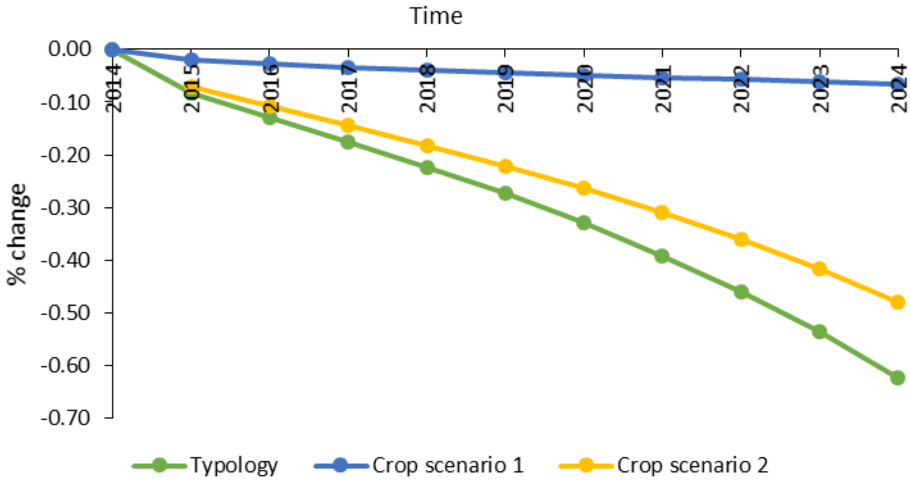

Figure 8e: Percentage change in the production of other crops

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

With the increase in maize production, there is a drop in the producer price of maize. As economic theory predicts, *ceteris paribus*, an increase in supply is usually accompanied by a fall in prices. Hence, this is not surprising. Figure 9a below shows that maize prices decline by 17.9%, 5.7% and 15.9% under typology, crop scenario 1 and crop scenario 2 respectively by 2024. A similar decline in the producer price is observed in the light manufacturing sector (mainly comprised of food processing), which is also accompanied by an increase in production in all scenarios thus conforming to economic theory. However, despite the increase in livestock production, the value-added producer price increases in all scenarios. Figure 9b below shows average increases of 3, 0.7 and 2.5% under typology, crop scenario 1 and crop scenario 2, respectively. The value-added price of trade services also increases in all scenarios despite the increase in production. While the production of other crops declines, the value-added producer price increases in all scenarios. This is expected because theory states that, *ceteris paribus*, a decline in output leads to an increase in prices due to the scarcity caused by decreased production.

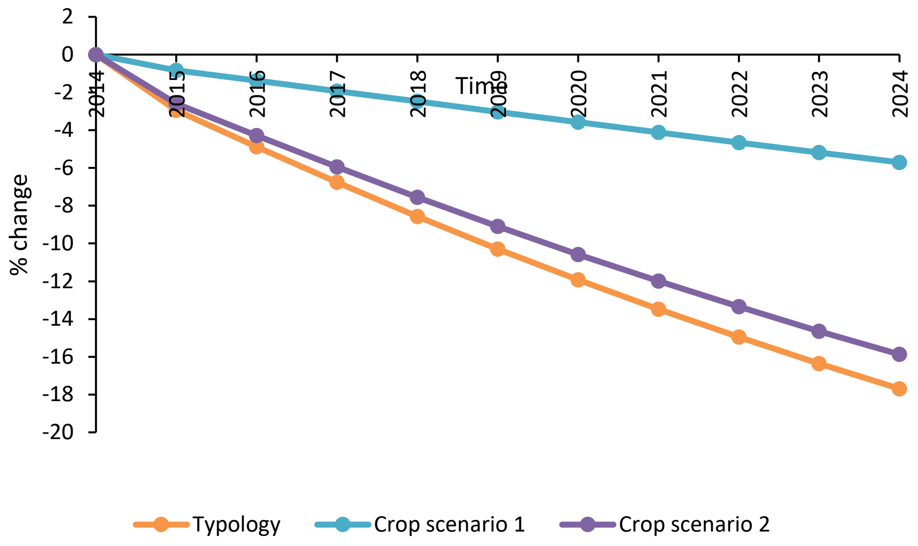

Figure 9a: Percentage change in producer price of maize

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

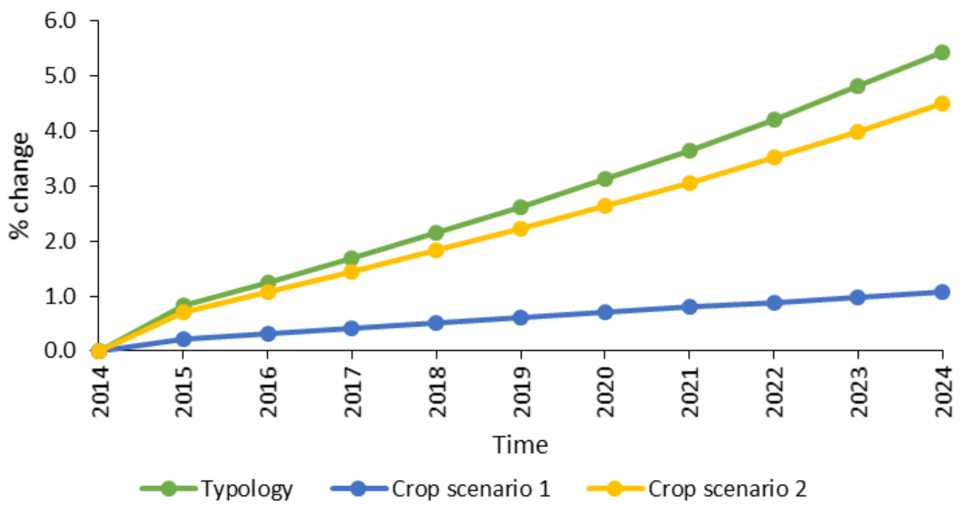

Figure 9b: Percentage change in producer price of livestock

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

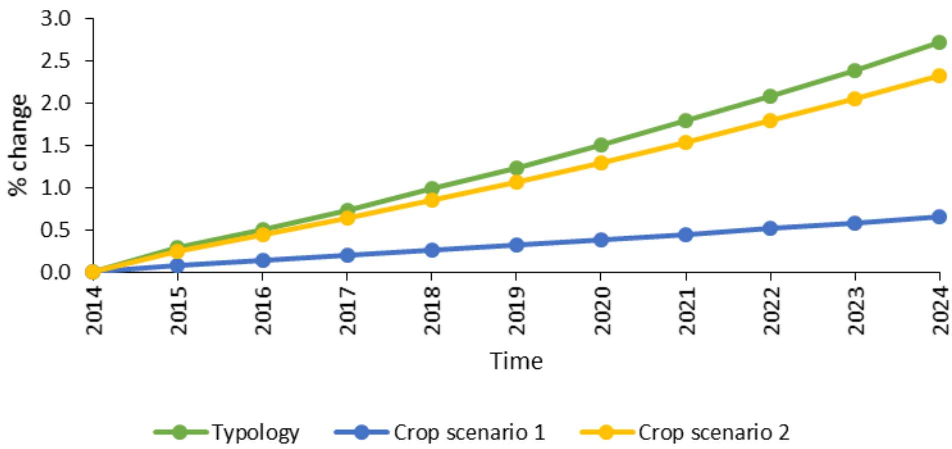

Figure 9c: Percentage change in producer price of other crops

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

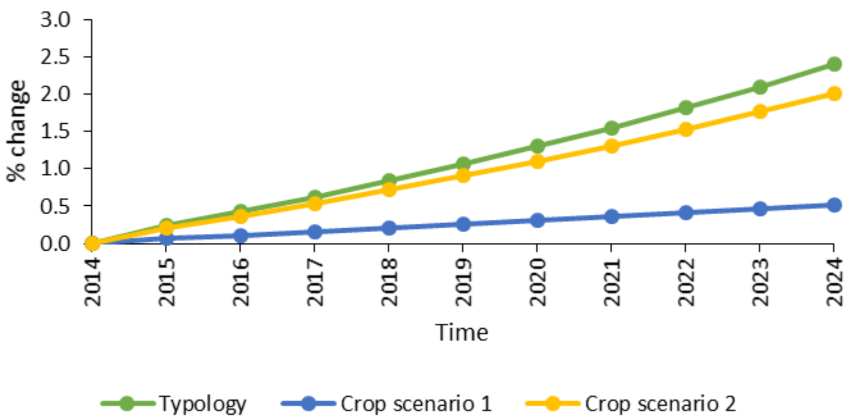

Figure 9d: Percentage change in producer price of trade services

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

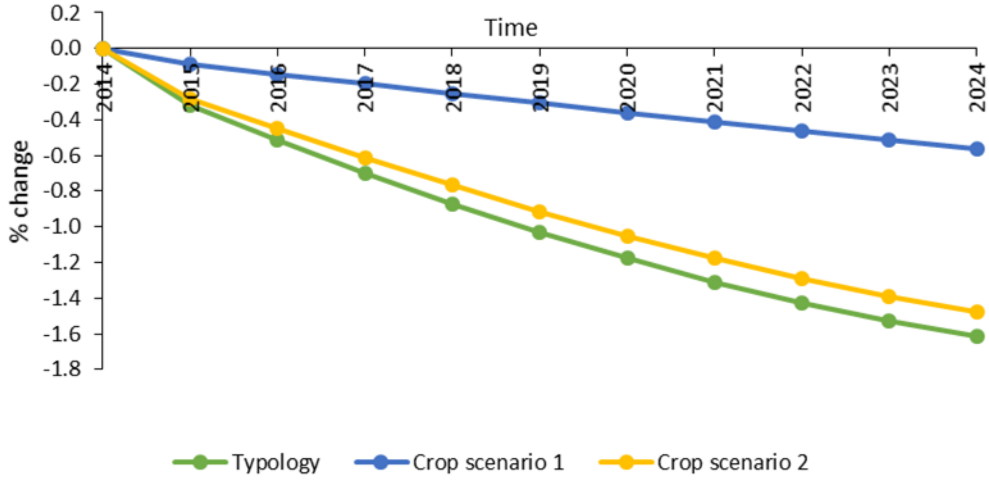

Figure 9e: Percentage change in producer price of light manufacturing

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

Technological innovation that leads to an increase in productivity is expected to be accompanied by increases in real wages. Following implementation of technological innovation, production of maize increased. This was followed by a decline in prices. From Figure 10a, we observe an increase in the real wages in the maize sector, which is in line with economic expectations, *ceteris paribus*. This increase is largest under typology scenario, which also recorded the greatest increase in production and the largest decline in producer prices. Figures 10b, 10c, 10d and 10e also show an increase in the real wages of all other sectors that have a linkage with the maize sector (livestock, other crops, light manufacturing and trade services) under all scenarios.

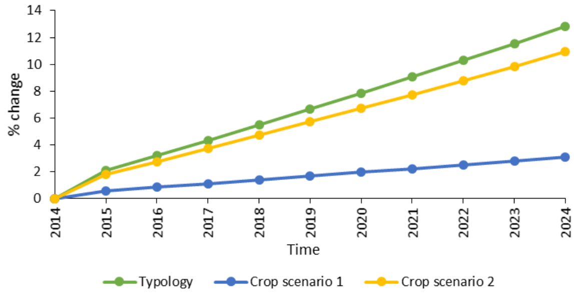

Figure 10a: Percentage change in real wages, maize sector

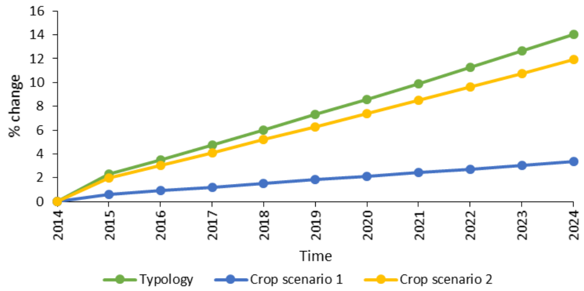

Figure 10b: Percentage change in real wages, livestock sector

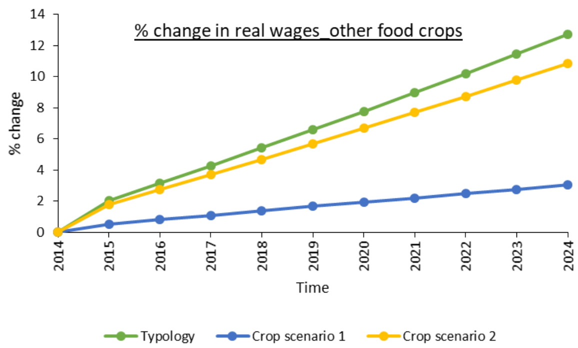

Figure 10c: Percentage change in real wages, other crops sector

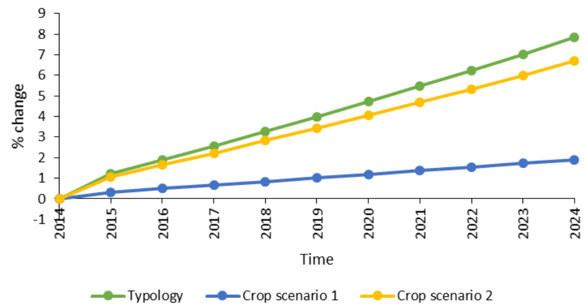

Figure 10d: Percentage change in real wages, light manufacturing

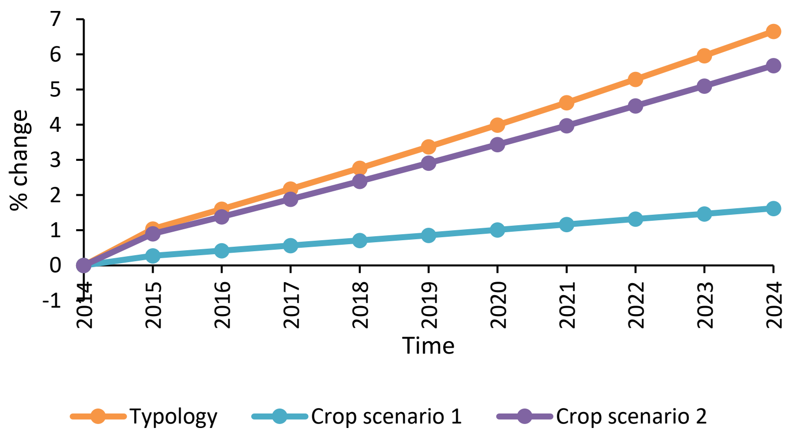

Figure 10e: Percentage change in real wages, trade services sector

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

Land was disaggregated into AEZs to take account of spatial heterogeneity. Table 3, above showed that AEZ 3 dedicates the largest portion of cultivated land to maize production. We therefore consider the returns to land in this agro-ecological zone. It is expected that the value of land, as a factor of production, would positively benefit from increased investment in management practices by becoming more productive. In our case, the increased use of fertilizer is expected to yield higher returns to land. However, from Figure 11 below, we observe an initial decline in the real return to land in the first period, after which returns to land begin to rise. The expected positive productivity effect can be offset by a fall in the value-added producer price of maize since land is a fixed factor.

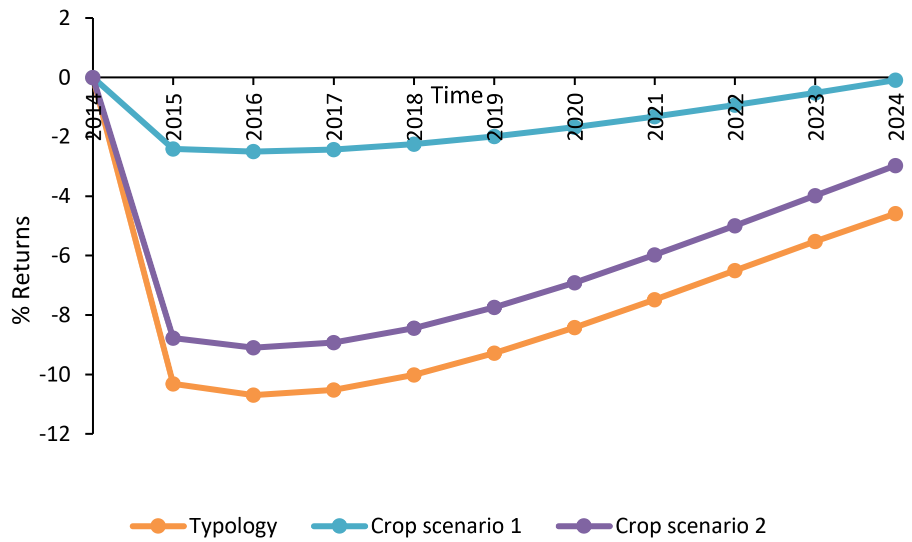

Figure 11: Percentage real return to land from maize production in AEZ 3

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

Despite the fall in the value-added producer price of maize, there is a significant increase in the real return to capital under all scenarios. We assume strong complementarity in production so that the high demand for capital is accompanied by an increase in the return to capital (Figure 12).

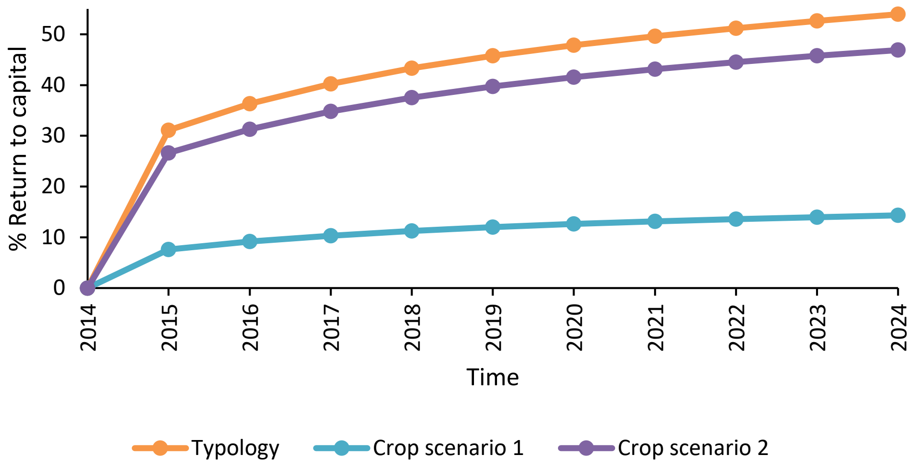

Figure 12: % real return to capital

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

5.1 Household welfare

In this section, we consider the change in household welfare because of price and income effects. Welfare is proxied here by Equivalent Variation as a percentage of initial income. EV is a monetary measure of the welfare effects of a price change.[15] Following an increase in the value-added price of maize, and improvements in household incomes, it is expected that this will result in a positive impact in household welfare. We are interested in establishing which households benefit more in terms of welfare improvement from the income and price effects. Figure 13 below shows a general improvement in welfare among all households by 2024 with rural households benefiting more compared to urban households. Comparing the change over time, Figures 14a – 14d show that both the rural and urban lowest income quintile have higher welfare gains compared to the upper urban and rural income quintiles. However, the lowest rural income quintile has the highest welfare gains averaging 7.3, 1.9 and 6.3% for, respectively, the typology scenario, crop scenario 1 and crop scenario 2. This is compared to the urban low-income quintile which averages 6.4, 1.5 and 5.2%, respectively, for typology, crop scenario 1 and crop scenario 2 and is the second highest beneficiary in terms of welfare gains.

With rising inequality in Malawi as depicted by an increase in the Gini coefficient from 0.39 in 2004 to 0.45 in 2011 (Mussa, 2017), our results show that the technological innovations are

[15]The Equivalent Variation is the change in wealth, at current prices, that would have the same effect on consumer welfare as the change in prices with income unchanged.

likely to lead to reduced inequality given that poorer households (both urban and rural) benefit more compared to non-poor households.

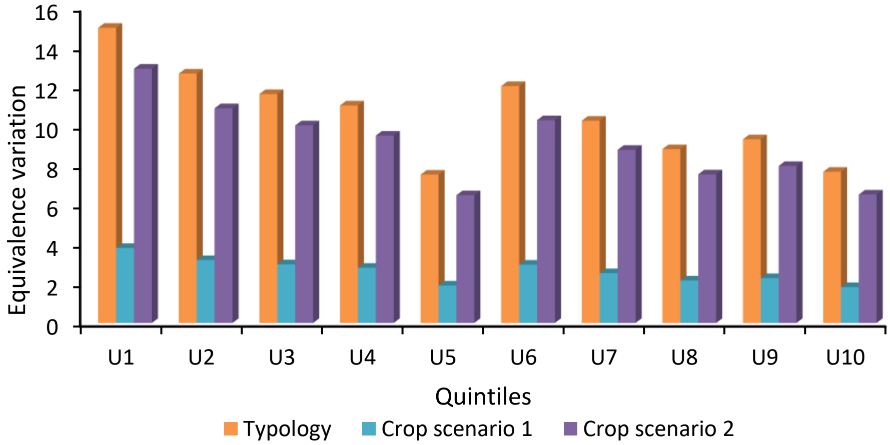

Figure 13: Equivalence variation_% change in the 10th period

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

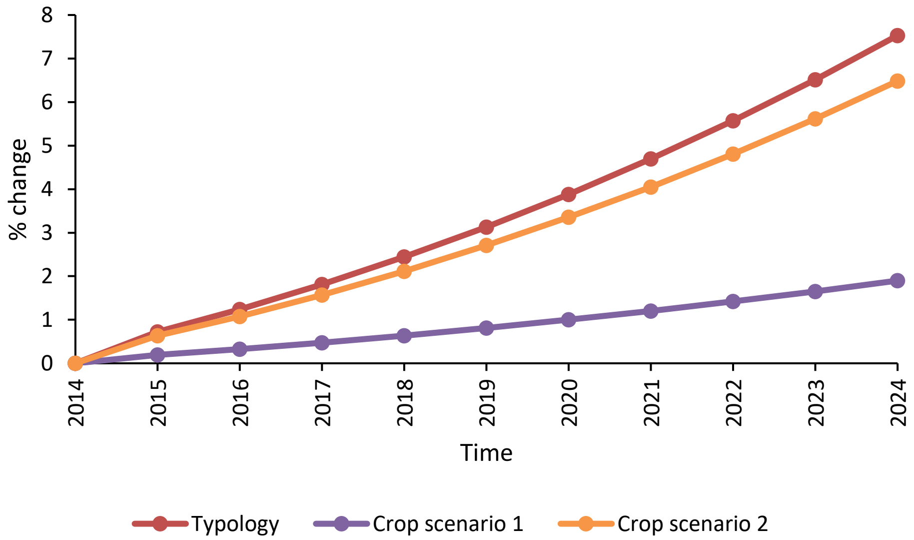

Figure 14a: % change in welfare - rural upper quintile

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

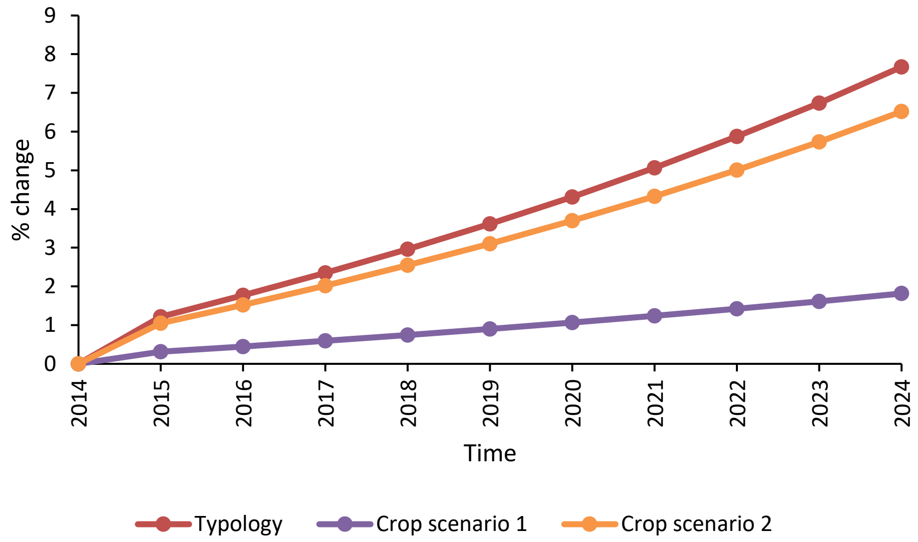

Figure 14b: % change in welfare - urban upper quintile

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

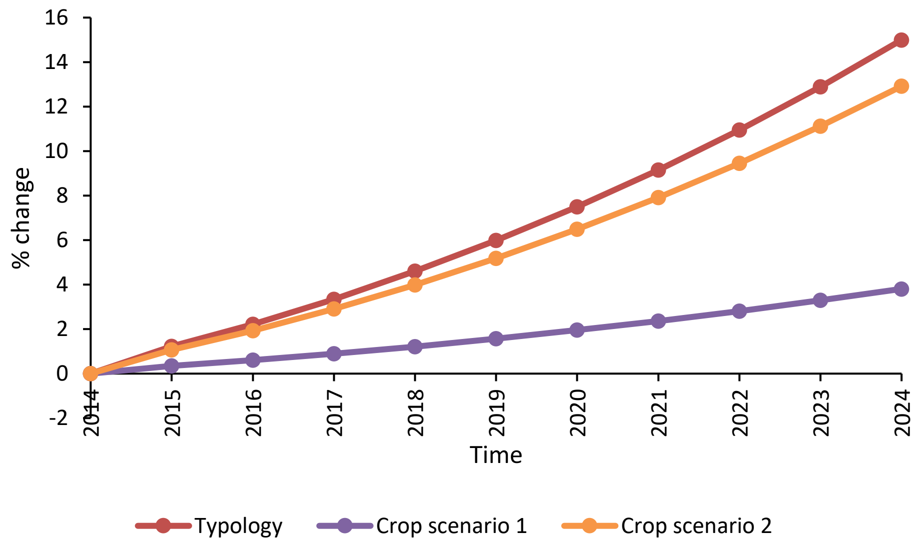

Figure 14c: % change in welfare - rural lowest quintile

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

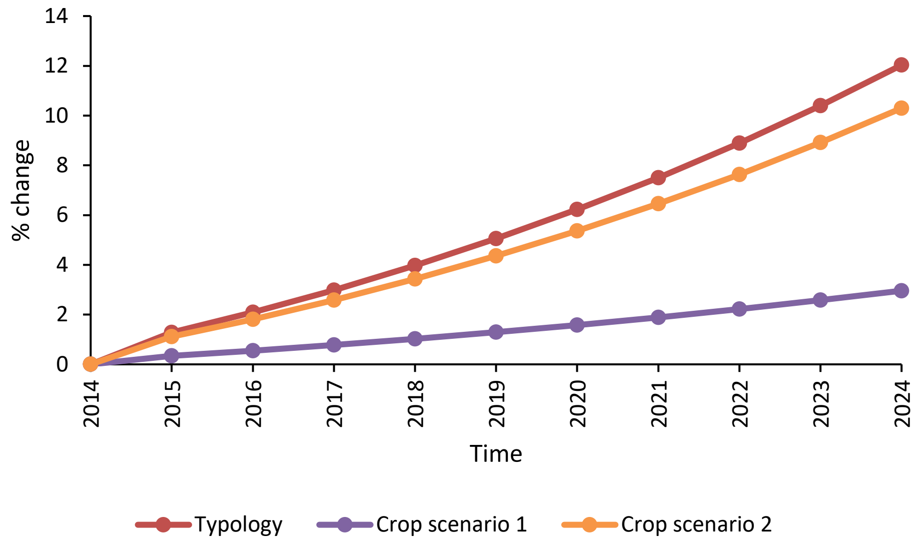

Figure 14d: % change in welfare - urban lowest quintile

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

5.2 Public expenditures required for implementing scenarios

Increasing productivity in the maize sector requires additional expenditures. To obtain the level (shares) of public expenditure needed to get the results of our three scenarios, we adopt a two-step approach. First, we compute for each of the scenarios (and the baseline), the total value added generated over the entire period of simulation. We then determine the changes between the scenarios and the baseline for the total value added generated. These total changes are then used as a target in a second step model and the share of public expenditures needed to achieve those targets are simulated. The increase in public expenditure enhances productivity and then production growth until the target is reached. We then model allocation of a 69% share of agriculture specific spending to the maize sub-sector, which gives an initial share of agriculture spending in public expenditure of 11% (FAO, 2015). Using this initial share in public expenditures, simulations were carried out to establish the required shares of public capital expenditure in the maize sector to achieve the productivity targets. Table 8 below provides the targeted change in total value added well as the changes in the share of public capital expenditures needed in the maize sector.

Table 8: Cost of scenarios

	Baseline		Typology scenario		
	Share of total agricultural expenditure (average)	Average Growth rate maize	Productivity target	Average Growth rate maize	Share of expenditure in maize sector
Elasticity	11%	2.2%	35.7%	8.5%	29.4%
1.5*Elasticity	11%	1.5%	35.7%	7.9%	23.1%

	Crop scenario 1			Crop scenario 2		
	Productivity target	Average Growth rate maize	Share of expenditure in maize sector	Productivity target	Average Growth rate maize	Share of expenditure in maize sector
Elasticity	8.15%	4.1%	15.3%	30.2%	7.8%	26.5%
1.5*Elasticity	8.15%	3.2%	13.9%	30.2%	7.1%	21.4%

Source: Authors' computations

Notes: Baseline entails a nitrogen application rate of 22kg/ha while retaining the existing management practices. Typology entails implementing an annual average growth rate of productivity for each AEZ required to operate on the potential production frontier. Crop scenario 1 entails introduction of new cultivars, a nitrogen application rate of 22kg/ha while retaining the current sowing dates. Crop scenario 2 entails increasing the nitrogen application rate to 60kg/ha, introduction of new cultivars and a change in the sowing dates.

Under the typology scenario, which estimates the growth rate in productivity needed to catch up with the production frontier, an increase of 36% in total value added generated is expected once all regions operate on their production frontiers. To achieve this target in production with the productivity increase simulated previously (Table 5), the share of public capital expenditure needed for the maize sector is 29.4% using the calibrated elasticity of total factor productivity to public expenditure. Under the crop scenarios, agricultural innovations are introduced in each AEZ coupled with changes in agricultural management practices aimed at increasing productivity through increased yields. The scenarios entail changes in nitrogen application (fertilizer use) and in yields whereby in each scenario, the rate of nitrogen application is combined with different sowing dates and introduction of new cultivars. Here, two scenarios were modelled. In the first scenario, maintaining the current cultivars and current sowing dates coupled with a single round of nitrogen application during sowing is expected to increase total value added by 8.15%. This will require a share of public capital expenditures of 15.3% in the maize sector. In the second scenario, an introduction of new cultivars and new sowing dates, as well as increasing nitrogen application (applied twice) from the baseline of 22kg/ha to 60kg/ha is expected to increase productivity by 30%. This will require a share of public capital expenditures of 26.5%.

Assuming that the maize sector is 50% more efficient, we modelled the expected shares of public capital expenditure. The expectation is that as one becomes more efficient, then less expenditures are required. This can be seen from the row labelled 1.5*Elasticity in Table 8, where we multiply the elasticity by 50%. Under the typology scenario, and targeting the same growth rates in value added, the required resources are now 23.2% as opposed to 29.4% when there was no increase in efficiency in spending. Likewise, under crop scenario 1, the share of public capital expenditures is now 13.9% compared to 15.3% without an improvement in efficiency. Finally, under crop scenario 2, the share of public capital expenditures falls to 21.4% compared to 26.5% without an improvement in efficiency.

The above results indicate the need for additional spending in the maize sector in Malawi to enable the country not only to improve the livelihoods of its rural population (the majority of which are smallholder farmers) but also for the growth of the economy.

6 Conclusion

This study has assessed the economy wide impact of technological innovation in the agricultural sector, specifically maize production in Malawi. The main data used for analysis was the 2007 Social Accounting Matrix, which was combined with results from crop modelling and typology studies. The analysis was based on modelling the impact of agricultural innovations using a CGE model developed for Malawi. The choice of CGE modelling was based on its ability to generate economy wide effects. The increases in yields (obtained from agronomic innovation scenarios) and the productivity growth rates needed to achieve production frontiers (obtained from the typology scenario) were thus incorporated into the CGE model to estimate the economy wide impacts.

The results show that under the baseline, the GDP growth rate is lower than that recorded in the simulation scenarios. This is also true for agricultural growth rates. However, unlike the GDP growth rate which declines over the years, agricultural growth rates are seen to increase over time especially under the typology scenario and crop scenario 2. Maize production increases but is accompanied by declines in the production of food and other crops. As noted however, the decline in the production of food crops is small (less than 1%) compared to the increases in maize production (reaching up to 70% under the typology scenario). While maize is grown by up to 97% of smallholder farmers and is a major staple food in the country, our results have shown that targeting maize alone may lead to an increase in agricultural growth rate but this does not translate to a sustained increase in GDP growth rate. Nevertheless, we see an improvement in livelihoods, which justifies continued targeting of the maize sector. However, this should not be at the expense of the other sectors of the economy.

The increase in maize production is also accompanied by a decline in the producer price of maize and an increase in real wages in all sectors considered in the analysis (other crops, livestock, light manufacturing and trade services). With the fall in the producer price of maize, there is a decline in the real return to land from maize production especially for AEZ 3, which has the largest area under cultivation for maize. However, there are larger returns to capital, reaching close to 50% under the typology scenario. Household welfare also improves, especially of rural households compared to urban households, and within each category the lowest income quintiles benefit more from the gains compared to households in the upper (non-poor) quintile.

Despite these positive impacts, there are cost implications. Public expenditures in the maize sector will have to increase to generate the increases in value added achieved under the various innovation scenarios. Malawi has already met the Malabo target of at least 10% of total expenditures allocated to the agricultural sector. Nevertheless, maize production, a major sub-sector of the agriculture sector is still below the production frontier (as seen from the typology analysis). Likewise, agricultural growth is below the Malabo target of at least 6%

growth. In fact, the growth rate of agricultural GDP is below 4% at the baseline over the entire period. Implementing the proposed innovations increases agricultural GDP to 5.7% by 2024 and agricultural GDP is at least 5% under typology and crop scenario 2 over the entire period.

From the above, one can draw important policy implications. The key role that agriculture and specifically maize production play not only in promoting growth of the overall economy but also in improving livelihoods cannot be emphasized enough. As such, there is a need for continued targeting of programs aimed at increasing maize productivity as this will reduce rural poverty.

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