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Economy-wide impacts of promising maize and wheat technologies on food security and welfare in Kenya

Amarendra Sahoo
Bekele Shiferaw
Sika Gbegbelegbe

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Abstract

A recursive dynamic economy-wide model incorporating productivity changes due to the introduction of promising maize and wheat varieties evaluates foresights for future food security, well-being and economic performance in Kenya. Adoption of promising new maize and wheat varieties not only increases overall economic growth and food availability, it also reduces import dependency and increases the welfare of vulnerable populations, especially rural households in lowland regions. Although maize-producing rural households in the highlands do not gain in terms of real incomes because of declining land income, they benefit from the increased food consumption stimulated by lower food prices. Promising maize technologies will have positive spill-over effect on all crops, mainly on wheat, and have larger positive impact on food security than the expected productivity change from the current promising wheat varieties. Although the lowland economy does not benefit from the adoption of new crop technologies, rural households in this region benefit the most in terms of increases in food and non-food consumption. The welfare gain in terms of food security is further amplified when technological change for the two crops is complemented by a reduction in the marketing costs, which facilitates market access for the increased surplus and further reduces domestic prices. With low marketing costs resulting from reduced trade and transport margins for these two crops, even highland maize producing households experience an increase in real income and the demand for both food and non-food commodities increase substantially, generating significant linkages between agriculture and other sectors.

Authors

Amarendra Sahoo
Fellow researcher
Partnership for Economic Policy (PEP)
Nairobi, Kenya

Bekele Shiferaw
PEP Executive Director
Partnership for Economic Policy (PEP)
Nairobi, Kenya

Sika Gbegbelegbe
Researcher
International Institute of Tropical Agriculture,
Lilongwe, Malawi

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I. Introduction

Like many Sub-Saharan African countries, agriculture in Kenya continues to be the main driver for poverty reduction and enhanced food security. Though agriculture plays a crucial role in accelerating economic growth and poverty reduction, and has been the main source of livelihood for almost 80% of the rural population, almost half of the country's population still lives below the poverty line (KNBS, 2008). Food production has not kept pace with the increasing population pressure, which has led to food insecurity and poverty in the country, especially in the arid and semi-arid regions of the country. The Strategy to Revitalize Agriculture (SRA) and Kenya Vision Maize 2030 have dwelt upon the importance of enhancing agricultural productivity and marketing systems to overcome food insecurity and poverty. While introduction of promising crop technologies is expected to increase agricultural productivity through higher yields and decreased transport margins by way of better marketing systems, improved transport and rural infrastructural development can also induce higher agricultural production and enhanced food security.

Traditionally, agricultural growth in Africa is generally achieved by cultivating more land, but there has been very little improvement in yields and barely any change in production techniques (NEPAD, 2013). Average crop yields, particularly for maize, in many Sub-Saharan countries range between 20% and 50% (for Malawi and Mali respectively) of farm demonstrations using 'best bet' technologies (World Bank, 2007). Increases in agricultural productivity can, however, provide a pathway out of poverty for rural and urban households in these countries (Faurès and Santini, 2008). Maize is the major staple food in Kenya, accounting for about 63% of total cereal caloric intake and about 35% of total food caloric intake, followed by wheat, accounting about 24% and 13% of total cereal and total food caloric intake respectively (FAOSTAT, 2011). Though average yields of aggregate cereals have increased from 1196 kg/ha in 1991-2000 to 1386 kg/ha in 2001-2013, mainly because of increased yields for wheat, yields of other cereals, including maize, have remained stagnant or even declined since 2000 (FAOSTAT, 2013). The average maize yield slightly dropped from 1654 kg/ha in 1991-2000 to 1636 kg/ha in 2001-2013 indicating that there was no effective change in maize yields. This is partly due to reduction of investment in agricultural research and development (Please and Thirtle, 2009). According to the FAOSTAT database, per capita wheat supply in a year remained almost stagnant at around 25 kg between 2000-2009 and increased to an average of 34 kg over 2010-2013. On the other hand, the average maize supply per capita in a year was around 83 kg between 2000 and 2006 and started declining, with an average of 77 kg from 2007 to 2013. Moreover, Kenyan agriculture remains primarily rainfed, adding to the uncertainty in crop productivity and food security.

In addition to technological change, many studies in Sub-Saharan Africa have found that improved road accessibility to agricultural extension as well as rural road networks can have significant impacts on farm productivity, agricultural production and poverty reduction (Kingombe and di Falco, 2012; Dorosh et al., 2012; Dercon et al., 2007). The findings by Kiprono and Matsumoto (2014), using longitudinal data along with a geo-referenced roads data, indicated that road improvement could make a key impact on alleviating poverty in Kenya through increased agricultural productivity and market participation of smallholder farmers. Using a sample of Kenyan maize growing households, Renkow et al. (2004) measured the size of fixed transactions faced by rural semi-subsistence households. Their econometric study showed that on average the ad valorem tax equivalent of the fixed transaction costs for households in marketing maize was 15.5%, while buying prices of maize were on average was 35% above selling prices.

Findings from studies using CGE models for Kenya with its agro-ecological zones suggest that that increasing only agricultural spending is not sufficient to meet the higher agricultural growth target; additional investments like road development coupled with rural market development are required to foster stronger growth in agriculture and are also effective in reducing poverty amongst Kenya's poorest households (Thurlow et al., 2007; Thurlow and Benin, 2008; Mabisa et al., 2012). Results from a static computable general equilibrium model for Mozambique indicates that gains from combination of improved agricultural technology and lower marketing margins exceed the sum of gains from separate scenarios (Arndt et al., 2010). Our study investigates the long-run food security and welfare impacts from the introduction of promising high yield potential and drought-tolerant maize and wheat technologies (based on high quality crop simulation studies), and the reduction of transport cost margins for these crops. The effects of these changes are investigated for households in different agro-ecological regions of Kenya. We also incorporate trends in productivity growth rates of these crops for three agro-ecological regions in the baseline.

Given the significant interlinkages between agricultural production and consumption, technological change and lowering transport margins are expected to have economy-wide effects through linkages with other sectors and through food and factor prices. A dynamic economy-wide computable general equilibrium (CGE) model with three ago-ecological regions is developed and applied to evaluate the impacts of shifts in crop technology from the prevailing maize and wheat varieties to promising varieties adapted to different agro-ecological conditions in Kenya. The promising maize and wheat technologies used in our study include drought-tolerant and high-yielding varieties of these crops. The new Drought Tolerant Maize for Africa Seed Scaling (DTMASS) funded by United States Agency for International Development (USAID) was born out of the progress made by the earlier Drought Tolerant Maize for Africa (DTMA) between 2007 and 2014 aimed at producing and adopting certified improved drought tolerant maize varieties in seven eastern (including Kenya) and southern Africa countries. The 'International Maize and Wheat Improvement Center' (CIMMYT) also develops wheat germplasm that combines high yield potential wheat under favourable conditions with tolerance to drought and water-limiting conditions. An increase in productivity is estimated from the Decision Support System for Agrotechnology Transfer (DSSAT) crop simulation tool which provides crop and agro-ecology specific productivity effects from new promising varieties relative to existing varieties of maize and wheat. In addition, we evaluate the effect of technological change in conjunction with a reduction in transport margins on maize and wheat. Reduction in transport margins for maize and wheat is considered as market facilitation or lower cost of market services to access the markets for these crops, which is expected to enhance the welfare and income of households. The main interest is to evaluate the economy-wide impacts of introducing the promising maize and wheat technologies along with the reduction in transport margins on the future scenarios for food security and well-being in Kenya to 2030.

The rest of the paper is organized into four sections. Section 2 outlines the database and the methodology, while baseline and alternative scenarios are discussed in Section 3. The baseline scenario considers trends in productivity growth rates using existing varieties of maize and wheat, while the technology scenarios incorporate the effects of productivity changes resulting from a shift to the upcoming and promising maize and wheat technologies, and a combination of both. In addition, we combine in the fourth scenario productivity change in the two crops with reduction of transport margins. The results are presented and discussed in Section 4. Section 5 concludes the paper, highlighting key policy issues.

II. Database and methodology

Unlike several impact evaluations carried out on agricultural technologies, the economy-wide modelling approach allows us to capture both direct and indirect general equilibrium effects. The most direct contribution of agricultural growth is through generation of higher income for farmers, but the overall effect can also be negative, e.g. if increased production lowers output prices, or production costs rise as input demand increases (Irz et al., 2001). Such effects are sometimes not systematically measured using a partial equilibrium approach commonly used in evaluating technology and policy impacts. de Janvry and Sadoulet (2002) use archetype CGE models to illustrate the direct and indirect channels through which an agricultural technological change can affect the rest of the economy and show that the relative importance of expected impacts varies with relative structural features of the economy, degree of openness of the economy and product substitutability and functioning of factor and output markets across sectors.

Other modeling work uses a partial equilibrium approach such as the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) which has spatial disaggregation for different regions and covers a range of agricultural production activities (Rosegrant et al., 2012). Though it uses a system of supply and demand equations to analyze baseline and alternative scenarios, as a partial equilibrium model, it ignores economy-wide interlinkages. Calzadilla et al. (2013) uses a combination of IMPACT-Water partial equilibrium model and a global computable general equilibrium model to improve calibration for expected changes in total agricultural productivity under climate change. One of their adaptation scenarios considers improvement in agricultural productivity by 0.5% per year across the board compared to the baseline.

The CGE model used in our study is also calibrated using data on projected rate of exogenous (non-price) growth trends in productivity of maize and wheat based on the IMPACT study. This projected trend reflects productivity growth driven by technological change, agronomic factors, etc. We use estimated biophysical yield differentials of existing varieties of maize and wheat for three agro-ecological regions from crop simulation model results for Kenya from DSSAT. As the focus of our study is on the impact of introducing promising maize and wheat varieties, we use more credible information, instead of assuming some hypothetical agricultural productivity improvement, from the crop simulation model results on the resulting productivity gains in the different agro-ecological region in Kenya. Adoption of promising maize and wheat crop technologies is expected to have differential impacts on the regional food economy as well as household food security across the region.

The economy-wide model developed here also captures the long-run impacts of productivity changes in maize and wheat sub-sectors on the economy, income and consumption of households, and most importantly on the long-run food security. The recursive dynamic CGE model solves sequentially for each period based on the economic behaviours and assumptions that link growth in one period to the next period till the year 2030. The model closely follows the single country dynamic PEP-1-t (Decaluwé et al., 2010) model, which assumes a multi-market and competitive economy. The benchmark dataset that describes the Kenyan economy is based on the 2007 SAM - Social Accounting Matrix (Thurlow et al., 2007; Thurlow et al., 2008; Mabiso et al., 2012).

The Kenya CGE model represents the structure of the economy in three agro-ecological regions: high rainfall, arid and semi-arid, with 25 commodities and 69 production activities across the three agrological regions (see Table A1 for detailed classification). It includes 10 crops including maize and wheat produced by 28 regional crop activities. Each commodity, e.g. maize or wheat, can be produced by several regionally disaggregated production activities, e.g. highland maize, lowland maize and midland maize. However, we assume a single national product market for each crop.

Kenya's agro-ecological zones differ in many ways. Table A2 briefly describes some of the characteristics of the observed Kenyan economy. Though highland and midland are almost equally populated, the share of the highland's economy in terms of real GDP at factor cost is almost one and a half times that of the midland region. Meanwhile, the sparsely populated lowland accounts for only 5% of national GDP. About 70% of the economy's agriculture is produced in the highlands and 25% in the midland. The highland region shares about 79% and 80% of the economy's maize and wheat production, respectively, while the midlands contribute about 20% and 18% of these crops. It should be noted that despite its adverse agro-ecological condition, the lowland still accounts for about 2% of economy's wheat production; however, livestock is the major source of income in this region, accounting for almost 22.5% of the economy's value of livestock.

Compared to other regions, the consumption basket of lowland rural households is dominated by food items (including livestock and processed food), at about 76%, while rural households in the highlands and midlands spend about 57% and 58% of their total consumption on food (Table A2). On the other hand, the share of food consumption is only 36% and 41% for urban households in the highlands and midlands respectively. Maize consumption is mostly a rural phenomenon, sharing about 4%-5% of the total food basket across the zones and wheat consumption is in fact negligible. Though household consumption of wheat is low in Kenya, its use as intermediate input is significant (Table A3); wheat is one of the highly imported crops in the economy besides rice and oilseeds. It is worth noting that household expenditures on processed food is the largest category of food expenditures across the regions. It is not surprising that livestock dominates the consumption basket of the lowland households (29%).

The output is produced in a nested production structure. Intermediate inputs and value added are combined in a fixed proportion to produce one unit of output of a sector. The value added in the agricultural sector has a constant elasticity of substitution (CES) between labour and the composite capital, which in turn is a CES combination of land, livestock and agriculture capital[1]. Value added in the non-agriculture sector is a CES function of labour and non-agricultural capital. Land is only used in the agricultural sector and is mobile between crop activities in a region. Skilled, unskilled and semi-skilled labour is combined in a CES production function to constitute composite labour. Labour is assumed to be mobile between sectors and within a

[1] A high elasticity of substitution (2.0) is used for the factor substitution assuming that in the long run flexible factors of production (e.g. land) are less constrained to a sector and they can, to a greater degree, replace each other and move to other sectors where they have relatively greater comparative advantage.

region. Land and unskilled labour are fully employed[2]. The model incorporates unemployment for skilled labour in an efficiency wage framework: employees set higher wages for skilled workers than the market-clearing wage in order to increase their productivity, and because workers are paid higher than the competitive wage there is unemployment. Increases in competitive real wages bring down the unemployment rate. The existing capital is sector-specific.

Households are classified according to regions, rural/urban and five expenditure quintile categories. Households own labour, land, livestock and capital as endowments. The existing sources of income and distribution of income in the national income by different household categories are given in Table A4. The highland households account for about 67% of the economy's personal income. Land cultivated by rural households in the highlands accounts for almost 82% of cultivated land nationally. Unlike in the highland region, labour is the primary source of household income for the lowland households, contributing around 57%. The distribution of factor ownership, particularly the cultivated land holdings, is expected to contribute to a large extent to the change in household income resulting from the change in factor prices due to the increased maize and wheat productivity.

Trade and transport margins are added to the domestic price of domestic production, as are imported commodities and indirect taxes, both of which are passed on to consumers as higher consumer prices. Consumers pay sales taxes on the top of the transport margin. The freight on board (FOB) export price paid by the foreign importers in the export market includes the trade margin that differentiates the FOB export price from the price received by the producer that produces export goods. The composite price (buying price) paid by consumers is the weighted sum of domestic and import prices. Similar to the domestic price, the price paid for imported commodities in local currency includes import duties, domestic indirect taxes and transport margins.

World prices are given for exports and imports. Given the world price of the competing exports and demand from the rest of the world, world demand for country's exports depends on the world price relative to the FOB price of exported commodity. Imports and exports are functions of world prices relative to domestic prices and the exchange rate. Exported and imported goods are differentiated from the domestically produced goods[3]. Total investment in nominal terms in the economy is adjusted to gross savings to balance the saving-investment closure. The balance of payment constraint incorporates fixed foreign savings in dollar terms, which equals net exports plus net foreign transfers, all in dollar terms. The exchange rate of domestic currency

[2] The assumption of full employment for the unskilled labour category adduces the fact that unskilled workers can engage themselves in many sundry activities at any wage.
[3] The elasticity of substitution between imported and local goods is assumed to be 3.0, indicating high degree of substitutability and a high degree of trade openness. We also assume an export elasticity of 3.0, indicating that a decline in the domestic commodity prices relative to world prices will lead to higher exports.

is determined by the market, and hence is endogenous in the model. The nominal exchange rate is chosen as numeraire[4].

In the long-run dynamic scenario, investment creates new capital for specific sectors. The volume of new capital investment is linked to the level of existing stock in private sectors[5] and the elasticity of investment with respect to the ratio between returns to capital and user costs (Lemelin and Decaluwé, 2007). The user cost of capital depends on the price of new capital, the rate of depreciation, and the rate of interest. The volume of new capital investments in public sectors (government services and water) is fixed. However, the aggregate public investment expenditure is evaluated by the endogenously determined price of new public capital[6]. The total factor productivity (TFP) of maize and wheat is updated for each year using the existing trends in exogenous productivity growth rates as used in the IMPACT model. In order to check the model consistency in the business as usual scenario (BAU), it is assumed that the economy grows at a constant population growth rate; the values of the exogenous variables are updated up to 2030 using the constant population growth rate.

III. Scenarios

The study aims to evaluate the outcomes and prospects for food security in the long run, up to 2030, resulting from introduction of new promising maize and wheat varieties as well as potential improvements in marketing systems. The impact of technological and market improvements are analysed under alternative scenarios in order to understand the individual and combined effects of different interventions. The following scenarios are developed for our analysis.

3.1. Baseline scenario

The baseline scenario represents a constant growth rate in the economy as well as in the exogenous productivity trends for maize and wheat without promising technologies over the 2007 to 2030 period. In the baseline scenario, the model is calibrated using the data on existing trends in exogenous productivity growth rates using the existing maize and wheat varieties in the three regions. All the exogenous variables except prices follow the annual population growth rate of 2.7%.

[4] When the nominal exchange rate is chosen as the numeraire and set to 1, the change in domestic prices defines the change in real exchange rate. The PEP CGE model allows that all our value-based results are in real terms.
[5] Activities in our model are classified into pubic (government) sectors and private (business) sectors.
[6] The aggregate quantity of new public/private capital investment expenditures may be destined to any public/business sector industry with a single price of public/business capital.

The baseline productivity of maize and wheat is determined on the basis of this information. The DSSAT crop simulation model estimates by CIMMYT provided the information on maize and wheat yields in high rainfall, arid and semi-arid regions, which are assumed to remain unchanged as climate change impacts are not included in this analysis. The maize and wheat productivity changes associated with the three agro-ecological regions for our base year of 2007 and baseline productivity growth rates till 2030 are computed using the IMPACT model exogenous growth rates (Rosegrant et al., 2012) and DSSAT simulations specific to the three agro-ecological regions (Table A6). Based on the DSSAT crop model, the bio-physical agro-ecological zone-based yield differentials of maize and wheat are incorporated in the baseline.

3.2. Technological change scenarios

This includes total factor productivity changes in maize and wheat production due to the introduction of promising varieties. Total factor productivity is defined as increases in output resulting from a promising crop technology holding, other farm inputs constant. New promising technology is introduced in the year 2015 and continues to 2030 assuming no climate change. The promising varieties would increase yield, and hence total factor productivity, over existing varieties (based on DSSAT simulation).

Current challenges to maize production in tropical Africa mainly consist of deficient soils, drought stress, and stresses from pests and diseases. However, CIMMYT, International Institute of Tropical Agriculture (IITA), and their partners are developing high-yielding maize germplasm well-adapted to the stresses affecting tropical maize (Shiferaw et al., 2011). In recent years, multiple improved drought-tolerant varieties have been released in several African countries with support from the DTMA project. In some countries, especially Mali, Nigeria, Ethiopia, Malawi and Ghana, the release of improved varieties has picked up pace in recent years, thanks to combined efforts from the DTMA project and national governments (Abate et al., 2015; Abate et al., 2013; Abate et al., 2014; Obeng-Antwi et al., 2013).

Following the success of the DTMA project, a new project, DTMASS has been launched in 2014. The project, which targets seed sectors, aims to facilitate access to certified drought-tolerant maize varieties for small scale farmers in seven countries in eastern and southern Africa. Recent controlled field trials imply that drought-tolerant maize varieties would bring yield gains varying between 20.5% and 40.6% for the maize grown in lowlands. The yield advantage from drought-tolerant maize varieties grown in mid-altitude areas would vary between 3.5% and 23% (Yoseph Beyene, personal communication). However, it is well known that yield gains from improved technologies are usually higher on controlled field trials than in farmers' fields. For maize grown in mid-altitude and lowland areas in Sub-Saharan Africa, it is estimated that farmers' yields are 36% and 16% of that obtained under optimal conditions, respectively (Lobell et al., 2009). Hence, the yield gain from drought-tolerant maize in controlled environment can be translated into gains varying between 3.19% and 6.32% for maize grown in mid-altitude areas in Kenya. For maize grown in lowland areas, the yield gains from drought-tolerant maize would vary between 1.25% and 8.21%.

This study assesses promising maize technologies which are in the pipeline to be released to farmers in Kenya. The improved maize varieties for highlands in Kenya would have a high-yielding trait since this zone receives ample rainfall for maize production. However, mid-altitude and lowland zones are more prone to drought and hence improved maize varieties targeted for these zones would combine high-yielding and drought tolerance traits. The yield gain should be higher in the highland zone compared to the other zones; based on the results from experimental field trial data, the yield gain varies between 4.28% in the lowland zone to 5% in the highland zone (Table A6).

Wheat production in Kenya is mainly hindered by biotic stress such as rusts and septoria (Shiferaw et al., 2013); in the lowland and mid-altitude zones, wheat is also affected by drought stress (Bhavani, personal communication). Promising wheat technologies which are assessed in this study involve varieties that are both high-yielding and drought-tolerant. The yield gain from promising wheat varieties varies between 2.92% in the lowland zone to 3.02% in the highland zone (Table 2).[7]

The impact of the improved wheat varieties on yields was simulated using the Decision Support System for Agrotechnology Transfer (DSSAT). The wheat model for Kenya was first calibrated and evaluated with baseline technologies which reflect the most common variety, Attila, used by farmers around 2005. Geo-spatial crop modelling, which involves simulating crop production over a region, was then used to quantify the impact of high-yielding drought-tolerant wheat in Kenya. More specifically, the geo-spatial crop model included the most common crop management practices used by Kenyan farmers, including fertiliser application which was taken from FAOSTAT. Soil characteristics were from the global World Inventory of Soil Emission (WISE) database adapted for DSSAT. The weather data consisted of measured data between 1950 and 2000 for Kenya. Drought tolerance was simulated by enhancing the plants' ability to extract soil moisture under water-stressed conditions.

The technology change scenarios include:

- **Scenario 1**: Increase in maize productivity due to improved varieties
- **Scenario 2**: Increase in wheat productivity due to improved varieties
- **Scenario 3**: Increase in joint productivity of maize and wheat

[7] In our model, as climate change is not explicitly modelled, we assume that the yield gains due to improved varieties of maize and wheat remain unchanged over the period.

3.3. Marketing costs scenario

In this scenario, we introduce a reduction of trade and transport margins for all crops on top of productivity changes from promising maize and wheat technologies. While improved productivity increases supply, reduction in trade and transport margins reduces the cost of intermediate input as well as prices on final consumption by households. The trade and transport margins could be interpreted as the suppliers' cost of marketing the product to the consumers or storage outlets, which are borne by the buyers. The gap between the consumer price and the producer farm-gate price due to the market margins may reflect some degree of market imperfections and imperfect competition (Arndt, 2010). These margins are introduced in the model as marketing service coefficients. Any investment in rural transport or market improvements benefits all agricultural products in terms of decreasing transport costs. Reduction in trade and transport margin is similar to the analysis of 'what-if' the targeted market facilitation or lowering cost of access to markets for crops are undertaken. This would lead to reduction in the purchase prices of these staples to both consumers and producers. According to Ariga and Jayne (2009) among other factors, a decline in the distance travelled by farmers to the point of maize sale, reflecting reduced distribution costs has contributed to growth in smallholder farm income and welfare in Kenya.

Our benchmark data in the 2007 Kenya SAM shows that trade and transport margins on all crops in Kenya constitute around 9% of the total value of crop products, and in the cases of maize and wheat these margins amount to about 7% and 8% of their respective market values. The share of trade and transport margins on maize and wheat is about 24% of the margins on all crops. We assume that maize or wheat produced in different regions faces a uniform average trade and transport margin (per unit market supply) irrespective of agro-ecological region. A study by Kirimi et al (2010) finds that spatial margins between surplus and deficit regions are low; wholesale prices in surplus areas are in the range of 90-95% of prices in the deficit regions. Hence, in our scenario we ignore this 5-10% price difference between surplus (highland and midland) regions and deficit (midland) regions. We simulate a 15% reduction in the marketing margin on all crops while simultaneously maintaining the productivity increase for the two crops[8].

- **Scenario 4:** Technological change for maize and wheat plus 15% reduction in trade and transport margins for all the crops

[8] It is assumed that investment on technology and marketing infrastructure has already been made at the time of simulation and cost of reducing market margins is not internalized in the model.

IV. Results

Three promising crop technology scenarios are introduced to quantify the impacts of promising maize and wheat varieties on future food security and wellbeing of households in Kenya. In addition, a combined scenario of increased productivity along with a reduction of trade and transport margins for these crops is simulated. The general equilibrium impacts are presented in the following sections. The changes in food security and welfare resulting from these alternative simulations are expressed in terms of percentage changes from the baseline in 2030.

4.1. Technological change scenario: increase in maize and wheat productivity

The economic impacts of increased agricultural productivity resulting from the promising maize and wheat varieties at the macro level are given in Table 1. Adoption of high yielding and drought tolerant maize varieties in Scenario 1 increases GDP by 0.13%, mainly due to increased agricultural output (0.43%). Overall maize output grows by 1.36%. The positive spill-over effects of the adoption of new maize varieties also generate growth benefits for other agriculture subsectors, leading to an increase in the wheat output (2.13%), with smaller increases in other crops, livestock and processed food. On the other hand, adoption of promising wheat varieties in Scenario 2 has a very small effect on GDP (0.02%) and agricultural GDP (0.09%), although wheat output rises significantly by 3.54%. Introduction of new wheat varieties also has marginal indirect effects on other non-wheat sectors, inducing growth in maize production by 0.19%. This is mainly because maize accounts for about 13% of agricultural GDP, while wheat constitutes only 2.3% (Table A2). Maize also accounts for about 17% of the value of total cultivated area in the economy compared to only 3% for wheat (Table A5). Given the importance of this crop in terms of its contribution to Kenya's food production and its land engagement, the impact of increased maize productivity is therefore higher than the impact relating to wheat. It should be noted that the production benefits across the agricultural sub-sectors partly result from reallocation of mobile factors of production, i.e. land and labour, within an agro-ecological region. An increase in joint productivity of maize and wheat in Scenario 3 shows 0.14% higher GDP with a 0.52% higher agricultural GDP. Wheat output increases significantly by 5.73%, followed by maize output (1.56%). The results clearly show an additive impact of results demonstrated in Scenario 1 and Scenario 2.

Adoption of promising maize and wheat technologies is expected to lead to higher food security and wellbeing as households experience gains in food consumption. An increase in maize production triggered by promising varieties in Scenario 1 not only significantly reduces the consumer price of maize (-3.02%), but also results in a drop in the overall consumer price index (-0.19%) and food prices (-0.43%), including the buying price of wheat (-0.14%). Aggregate household consumption increases by 0.17%, leading to growth in food and non-food consumption by 0.21% and 0.13%, respectively. Aggregate household maize consumption increases by 0.74%, followed by a 0.14% increase in wheat consumption. On the other hand, adoption of new wheat technology in Scenario 2 has a marginal positive impact on overall household consumption (0.03%) and food consumption (0.04%), though wheat consumption increases by 0.45%. Although increased wheat productivity reduces the consumer price of wheat by 1.38%, unlike the case of Scenario 1 consumers do not gain much from price effects in other non-wheat consumption goods. However, joint productivity growth in maize and wheat in Scenario 3 significantly reduces the consumer prices of all food products (-0.44%), including maize and wheat (-2.97% and -1.52%, respectively) resulting in a fall in the consumer price index (-0.18%). In addition, overall food and non-food consumption increases by 0.24% and 0.16%, respectively, with an increase in maize and wheat consumption by 76% and 59%, respectively.

Food availability per worker as an index of food security also increases in all the technology scenarios. However, introduction of new maize varieties has a greater impact on the food availability per worker (0.32%) than the impact of wheat varieties (0.09%). Joint productivity change in Scenario 3 leads to an even higher increase in food availability per worker (0.41%) compared to other individual technological scenarios. In our model we assume that there is no excess supply of unskilled labour as workers can be absorbed in any available low-skill jobs. However, we assume unemployment of skilled labour in the economy. Skilled workers are employed mostly in the industrial and service activities. The unemployment rate declines the most when new maize technology is adopted (-0.14%) in Scenario 1 due to the increased industrial activities, while it drops marginally by 0.01% with the increased wheat productivity in Scenario 2. The combined technological change in Scenario 3 results in a larger decline in the unemployment rate (0.15%).

As compared to maize, wheat is a highly tradable commodity in Kenya where imported wheat comprises almost 34% of total supply (Table 1 and Table A3). In Scenario 1, increased domestic maize production and lower domestic prices relative to world markets lead to a higher quantity of Kenyan output demanded by the world, increasing maize exports (3.16%) and wheat exports (1.82%), and a significant 7.98% decline in maize imports. On the other hand, although exports of wheat increase significantly by 4.26% and imports decline by 3.24% due to the adoption of promising wheat varieties in Scenario 2, it only has a marginal aggregate impact on net trade, indicating a weak impact of wheat technologies on other sectors in the economy. The joint productivity change in maize and wheat in Scenario 3 stimulates significant increases in exports of both wheat (6.14%) and maize (3.2%). On the other hand, imports of maize decline significantly (-2.97%) as do those of wheat (-1.52%), contributing to reduced dependence on food imports. However, like Scenario 2, Scenario 3 only has a marginal impact on aggregate trade.

We also present the scenario results disaggregated by the macro impacts across different agro-ecological zones and household groups. Table 2 reports the disaggregated GDP impacts across the agro-ecological regions. With the introduction of promising maize varieties in Scenario 1, highland maize production increases by 1.41% while wheat output also increases by 2.14%. This is mainly because increased maize productivity crowds in resources, particularly into the wheat sector, a sector which is highly import substituting and where imports constitute a large share of national supply. It seems that the higher maize productivity also cause substantial crowding in of resources into wheat production in both midland and lowland regions. Although adoption of improved wheat varieties in Scenario 2 increases the wheat production across all the regions (3.54%, 2.65% and 2.41% respectively), it has very negligible impacts on the aggregate economic output at the regional level, due to its weak indirect output effects on the rest of the sectors. Similar to Scenario 1, in Scenario 3, the highland region benefits the most as production of maize, wheat and other crops increases by 1.61%, 5.74% and 0.39%, respectively. However, despite a comparable gain in wheat output in midland and lowland regions (2.85% and 2.47% respectively), the overall output gain in these regions is very small, mainly due to decline in maize activities.

Table 3 presents the demand and factor income across the agro-ecological zones. Because of efficiency gains resulting from technological change, a higher amount of output can be achieved with the same level of factors of production nd intermediate inputs. Production of maize becomes less resource intensive with the introduction of improved maize varieties in Scenario 1, significantly reducing the demand for labour, land and capital in maize activities across regions. However, land as a mobile factor of production is allocated to other crop activities, mainly to wheat; and labour to all other sectors including the non-farm activities., the decline in the demand for land in maize production in the midland (-10.05%) and lowland (-5.30%) regions is absorbed by other crop activities. Similarly, a significant decline in the demand for labour in the midland (-6.27%) and lowland (-10.97%) regions is reallocated partly to non-crop activities, indicating a possible low absorption of unemployed labour[9]. Factor income from land decreases for all the regions due to the declining demand for land in maize activities; highland, lowland and midland regions experience a decline in their land income by -0.46%, -0.48% and -0.49%, respectively. Nationally, factor income from land decreases by 0.47%. However, factor income from labour and capital increases marginally.

[9] We assume unemployment exists only for skilled labour. Unskilled labour with a low reservation wage is assumed to be fully employed.

On the other hand, the adoption of new wheat varieties in Scenario 2 results in an increased demand for all factors of production engaged in both maize and wheat activities in the highland region, but at the cost of other crops and non-crop sectors in this region (Table 3). However, demand for labour and land in wheat activities declines in both midland and lowland regions. The earnings from all the factors of production increase in this scenario, although marginally. Finally, enhanced productivity of maize and wheat in Scenario 3 leads to factor demand and income that is dominated mainly by the effects of maize technology, and hence follows a similar pattern as in Scenario 1. It is to be noted that even if the factor income from land declines in Scenario 1, the decline is moderated in Scenario 3 by a marginal increase in rent to land stimulated by the wheat technologies in Scenario 2.

Table 4 captures the change in real consumption or real income, and food and non-food consumption for all household groups across the agro-ecological regions. Under Scenario 1, the relative decline in factor income particularly from land in the maize activities adversely affects earnings, especially the total real consumption budget, i.e. the real income, of households in the bottom three quintiles in the rural highland region who are heavily engaged in maize activities[10]. Consumers benefit from the decline in composite prices of maize and thus increase their consumption of maize significantly. The bottom three rural household groups in the highland region seem to have cushioned their food consumption by reducing non-food consumption, which leads to a modest decline in total consumption. The rural households in the lowland regions benefit the most in terms of their higher consumption of maize and all other food crops.

The overall effects of wheat productivity changes on factor prices in Scenario 2 seems to have generated higher real household income (Table 4). Although poor households in the rural highlands are not expected to cultivate much wheat, under the assumption that land is mobile, it is noticed in Table 3 that the increased wheat productivity induces additional demand for land in both wheat and maize activities, resulting in an increase in the real income of these poor households. Consumption of wheat as a major staple food increases for all households due to the declining wheat prices. Despite the unfavourable price effects from non-wheat sectors, the modest rise in factor income leads to a moderate increase in the consumption of all food and non-food items across all household groups.

The increased productivity of maize and wheat in Scenario 3 moderates the negative factor income effect for the bottom three quintiles of rural households in the highlands who suffer an income loss in Scenario 1. This is due to the positive factor income effect resulting from

[10] If land is not allowed to be mobile, i.e. fixed in maize and wheat activities, it is noticed that the negative income effect is even higher than if land is flexible to be used by other crop activities. With the increase in maize productivity, even the bottom four quintiles of households in the highlands would experience a decline in real income. Improved wheat productivity (Scenario 2) would also not benefit these household groups in terms of real income (even the lowest quintile household group would suffer a marginal decline in real income).

the increased wheat productivity. This leads to a much reduced decline in total real income for the bottom two rural household groups in the highland region. Consumer prices of all food products decline in this scenario. Despite the modest decline in total consumption for the bottom two rural highland household quintiles, all households benefit from the declining consumer prices of food items with an increase in food consumption, including maize and wheat. Despite a marginal increase in non-food prices, households increase their consumption of non-food products because of increased real income. Benefits are significant for lowland rural households, the poorest regions, as they gain the most in terms of increased consumption of maize and wheat as well as total food consumption relative to other households.

4.2. Technological change combined with reduced trade and transport margins

Reduction in trade and transport margins across crops lowers the marketing costs and hence, buying prices of the staples. This will in turn affect final household consumption as well as intermediate consumption, e.g. seeds used in production. Lowering trade and transport margins of all crops (15% reduction) together with productivity growth for maize and wheat is expected to generate a higher positive impact on maize and wheat production. This policy which reduces the unit cost of production due to lower prices of intermediate inputs is expected to increase consumption of staples due to lower domestic prices. In order to understand the incremental effect of the reduced marketing margins, the results from this Scenario are presented in terms of differences compared to Scenario 3 (joint technological change).

Table 1 shows that on account of the reduced trade and transport margins, agricultural GDP is about 0.33% higher than in Scenario 3. Industrial output is also 0.45% higher, including a 0.66% gain in processed food output because of its dependence on intermediate inputs from the agricultural sector. The highest output gain accrues to wheat sector (1.66%), followed by maize (0.68%). However, national GDP is only marginally higher than in Scenario 3 (0.01%) mainly due to lower output in the service sector (-0.18%) which includes trade and transport activities. Households benefit from the decline in the consumer price index (-0.33%) and increase their consumption by 0.38%. Food prices drop by 0.61%, with a major decline in consumer prices of maize (-0.93%) and wheat (-0.1.09%). There is an increase in both food (0.46%) and non-food (0.30%) consumption. Household consumption of maize and wheat increases more than other food items; national consumption increases for both maize (0.52%) and wheat (0.74%). The reduction in the trade and transport margins also helps elevate the food security index as food availability per worker is 0.52% higher than in Scenario 3. Unlike the technology change scenarios, the economy experiences a slight increase in the unemployment rate for skilled labour (0.02%) due to the slump in service sector activities, where most of the skilled workers are engaged.

Reduced marketing margins bring about higher export competitiveness for both crops, although Kenya remains net importer of both crops (Table 1). Relative to Scenario 3, exports increase for both maize (1.05%) and wheat (0.41%) as domestic prices of these staples become cheaper than their export prices. However, total exports from the economy decline slightly. It should be noted that the reduction in trade and transport margins also makes buying prices of imported crops cheaper. Import prices decline relative to domestic prices for both maize (-1.24%) and wheat (-1.49%), resulting in higher imports of both maize (0.91%) and wheat (1.44%) compared to Scenario 3. However, import dependency of maize and wheat still declines (-6.90% and 0.51% respectively) once the joint effect of technological change and reduced market margins of these staples are estimated. Overall imports at the national level decline slightly (-0.05%).

Looking into the effects by agro-ecological zone in Table 2, unlike the technological change scenarios where the positive performance of highland regions dominated the output effect of the economy, the reduction in trade and transport margins reduces the output of this region. This can be attributed to the declining non-crop sector output in the highlands as a result of the reduced trade and transport activities. However, all crop activities in the highland region benefit from the reduction of trade and transport margins, resulting in highest increase in wheat production (1.66%) followed by maize (0.69%). Production of these staples, in fact, declines marginally in lowland region. However, there is an increase in output of crops other than maize and wheat, but this is not sufficient to offset the declining output from other sectors, resulting in a 0.10% drop in the aggregate output of this region. Only the midland region experiences a modest gain in output (0.11%), mainly because the improvement in regional output seems to be spread over several sectors except for a marginal decline in wheat output.

Table 3 shows that compared to Scenario 3, a reduction in the trade and transport margins of crops actually increases the factor income from land due to increased crop activities and lowers the earnings from capital due to the reduced demand for non-agricultural capital.

Unlike the previous cases, the increase in joint maize and wheat productivity together with a reduction in the transport margins in Scenario 4 would bring a greater gain in real income for all households compared to the technological change in Scenario 3 (Table 4). The bottom two rural household quintiles in the highlands, who suffer a small decline in real income in Scenario 3, in fact, experience the highest relative increase in real income. As a result, the households in the rural highland region, particularly the households belonging to the bottom three quintiles, have the highest gain in both food and non-food consumption. In general, relative to the gains from the technological change scenarios, the increased real income and drops in prices of both food and non-food commodities stimulated by the reduction in trade and transport margins for all crops bring significant gains in terms of household consumption and food security. Moreover, rural households experience higher benefits in terms of real income and consumption (food and non-food) relative to their urban counterparts.

V. Conclusion

The study evaluates the long-run economy-wide impacts of productivity change in maize and wheat and lowering of trade and transport margins for all crops in Kenya using a recursive dynamic computable general equilibrium model. The model considers linkages and flows between economic sectors in three agro-ecological regions: highland, midland and lowland. The potential of maize and wheat technologies in enhancing the wellbeing of the households in the long run is simulated through the introduction of promising varieties as well as lower trade and transport (or marketing) margins. We update our baseline scenario for maize and wheat by introducing the trends in exogenous productivity growth rates to 2030 based on IMPACT data. The change in productivity due to promising varieties over the existing cultivars is estimated using a crop simulation model (DSSAT undertaken by CIMMYT). In addition to the technology scenarios where increases in the productivity of maize and wheat are implemented, we consider a scenario that combines increased productivity with a reduction in the transport margin for the two crops.

An increase in maize productivity resulting from introduction of promising maize varieties increases maize production in the economy by 1.36% with significant positive effects on wheat output (2.13%) and on other agricultural sub-sectors as well. The maize yield improvements crowd in resources to the wheat sector, which is relatively more import-substituting, resulting in relatively higher price advantages for the resources in this sector. The economy gains in terms of growth in real GDP (0.13%), declining cost of living in terms of consumer price index (-0.19%) and food prices (-0.43%), gain in overall food consumption (0.21%) and food security index in terms of food availability per worker (0.32%). Declining domestic prices with increased maize output results in a significant decline in maize imports and increase in exports. The highest economic growth accrues to the highland region followed by a marginal gain for the midlands. However, the overall lowland economy and its maize sector do not benefit from the introduction of promising maize technologies; rather, due to the crowding in of resources from maize to the wheat sector, wheat production in this region increases. An increase in maize productivity with subsequent reduction in factor demand and prices adversely affects the real incomes of the bottom three quintiles of households in rural highland areas, who are highly engaged in maize production. However, these household groups cushion the decline in their real income by slightly reducing their non-food consumption. All household groups gain in terms of increased consumption of almost all food items. More importantly, the rural households in the poorest region in the country (lowlands) benefit the most in terms of food consumption.

Introduction of promising wheat varieties only has a marginal positive impact on the aggregate economy (0.02%), although wheat output marks a significant increase (3.54%). The overall food availability level improves marginally by 0.09%. Despite the significant drop in the buying prices of wheat (-1.38%), there is an insignificant impact on the overall consumer price index of the economy. Wheat exports increase significantly (4.26%) while its imports decline by -3.24%. Overall wheat consumption, triggered by declining wheat prices, improves by 0.45%. However, total food consumption improves by about 0.04%. The negative impact on the factor demand in agricultural activities resulting from introduction of promising wheat varieties is relatively less severe than that resulting from the adoption of new maize varieties. Unlike the increased maize productivity scenario, increased wheat productivity, in fact, induces factor demand in the highland wheat activities as wheat is more import substituting and its weighted factor prices do not fall as much as in maize technology scenario. Income from all factors increases, albeit to a small extent, leading to marginal increase in the real income of all household groups. Household consumption of wheat and other non-wheat items also increases primarily due to declining wheat prices as well as to gains in real income. Comparing both the scenarios, and whereas both staples are important for food security, the results show that the current promising maize varieties will have a greater impact on food security and welfare than the current promising wheat varieties.

Nevertheless, joint introduction of maize and wheat varieties will have a much stronger effect on overall economic growth (0.14%), particularly on production of maize (1.56%) and wheat (5.73%). Economic wellbeing is enhanced as the consumer price index drops by -0.18% together with increase in food availability per worker (0.41%). Import dependencies for both of these staples decline significantly, while their long-run export competitiveness increases. Consumers benefit from the declining food prices including a significant drop in the purchase prices of both staples. Overall food consumption in the economy improves by 0.24%, with the highest gain coming through increased maize consumption. The highland region gains the most in terms of output growth and food crop production due to significant increases in wheat and maize output. The midland economy experiences only marginal gains, mainly due to the increased wheat production. On the other hand, the combined effect of increased productivity of maize and wheat is able to moderate the adverse income effect of increased maize productivity for the bottom three quintile household groups in rural highlands. Both income and price effects benefit the households by inducing both food and non-food consumption. Like the improved maize technology scenario, rural households in the lowland region experience large gains in consumption compared to other households in the economy.

The reduction in trade and transport margins of all crops in combination with productivity improvements further enhances the positive impacts on households. But, the overall effect on economic growth is marginal. Although both agricultural and industrial output gain in this scenario, overall GDP is only 0.01% higher than in the previous joint technological change scenario because of declining service output. Consumers experience improvements in their wellbeing in terms of increased food consumption as overall food availability increases (0.52%) with a drop in the general consumer price index (-0.33%) including food prices (-0.61%) over the previous scenario. However, import dependency of staples does not decline as imports become relatively cheaper due to the reduced trade and transport margins. Although returns to capital decline in this scenario due to reduced demand for non-agricultural capital, increased crop activities prompts a significant increase in land income. All household groups therefore experience an increase in real income compared to other scenarios. The positive income effect along with reduced consumer prices enhances food consumption for all households, particularly the rural households belonging to the bottom three quintiles benefitting the most from these joint interventions. Unlike the other scenarios, the increase in real income also leads to increased non-food consumption for all the households, indicating significant income linkages with the non-farm sectors resulting from the integrated interventions that combine technical change with markets.

This analysis has shown that future food security in Kenya can be enhanced through technological change and increased productivity growth for these crops. This effect can be increased further if supported by a policy shift which reduces the trade and transport margins on all crops facilitating their market access. Productivity growth from promising varieties enhances food security, both in terms of availability and consumption across all the regions. The consumption and food security effects are much stronger for maize than wheat varieties. More importantly, import dependency for the major staples declines significantly, while their respective export competitiveness increases. Despite a marginal decline in the real incomes of the poorest maize producing highland rural households in most of the scenarios, their food consumption, in fact, increases. Moreover, households in the poorest region of the country (lowland), where the suitability of the new maize and wheat varieties is limited, experience the highest gain in consumption, both food and non-food, primarily through declining food prices and positive income effects. The food security and welfare effects are significantly enhanced when technological change is complemented by improvements in market access for crops. This increases consumption of both food and non-food commodities and improves competitiveness and food security for major staples benefiting the rural households more than their urban counterparts.

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Appendix-1

Table 1: Impact on GDP and other macro indicators in 2030

	Initial level GDP (million Ksh)	Baseline growth rates (%)	Changes from baseline level in 2030 (%)			% change over the Scenario 3
	2007	2007-2030	Simulation 1	Simulation 2	Simulation 3	Simulation 4
Total GDP at factor cost	1,603,196	2.70	0.13	0.02	0.14	0.01
Agriculture	424,636	2.72	0.43	0.09	0.52	0.33
Maize	50,138	2.81	1.36	0.19	1.56	0.68
Wheat	9,056	3.28	2.13	3.54	5.73	1.66
Other crops	240,930	2.69	0.30	-0.04	0.27	0.23
Livestock	86,508	2.70	0.25	0.02	0.27	0.30
Other	38,004	2.69	-0.07	-0.02	-0.09	0.10
Manufacturing	175,658	2.70	0.16	0.04	0.20	0.45
Processed food	49,933	2.70	0.45	0.14	0.60	0.66
Other industry	125,726	2.70	-0.01	-0.02	-0.03	0.33
Services	1,002,901	2.69	0.01	-0.01	-0.005	-0.18
Real household consumption	1,389,420	2.71	0.17	0.03	0.20	0.38
Food consumption	670,645	2.71	0.21	0.04	0.24	0.46
Maize	40,022	2.72	0.74	0.02	0.76	0.52
Wheat	596	2.74	0.14	0.45	0.59	0.74
Non-food consumption	718,775	2.70	0.13	0.03	0.16	0.30
Public consumption	311,221	2.74	-0.07	-0.03	-0.10	0.02
Investment	368,018	2.69	-0.09	-0.02	-0.11	0.00
Exports	413,081	2.69	0.13	-0.05	0.07	-0.04
Maize	151	2.84	3.16	0.12	3.29	0.41
Wheat	304	3.26	1.82	4.26	6.14	1.05
Imports	703,356	2.69	0.01	-0.03	-0.01	-0.05
Maize	3,719	2.59	-7.98	0.35	-7.66	0.92
Wheat	5,958	2.81	1.43	-3.24	-1.86	1.44
Prices of export goods relative to domestic			0.07	-0.01	0.07	0.11
Maize			2.10	-0.10	2.00	0.81
Wheat			-0.45	0.69	0.24	0.77
Prices of import good relative to domestic			0.13	0.003	0.11	-0.03
Maize			3.56	-0.05	3.50	-1.24
Wheat			0.27	2.54	2.81	-1.49
Consumer Price index			-0.19	0.007	-0.18	-0.33
Food prices			-0.43	-0.01	-0.44	-0.61
Maize			-3.02	0.05	-2.97	-0.93
Wheat			-0.14	-1.38	-1.52	-1.09
Non-food prices			0.04	0.02	0.06	-0.08
Food security index[1]			0.32	0.09	0.41	0.52
Unemployment rate (%)[2]	8.9	8.9	-0.14	-0.01	-0.15	0.02

[1] Defined as food availability per workforce
[2] Unemployment of skilled labour

Table 2: Impact on GDP by agro-ecological region in 2030

	Changes from baseline level in 2030 (%)			% change over the Scenario 3
	Simulation 1	**Simulation 2**	**Simulation 3**	**Simulation 4**
Total GDP	0.13	0.02	0.14	0.01
Total highland GDP	0.18	0.02	0.20	-0.01
Maize	1.41	0.19	1.61	0.69
Wheat	2.14	3.54	5.74	1.66
Other crops	0.45	-0.06	0.39	0.19
Non-crop sectors	-0.09	-0.07	-0.16	-0.12
Total lowland GDP	-0.02	-0.02	-0.03	-0.10
Maize	-0.33	0.01	-0.32	-0.09
Wheat	0.06	2.41	2.47	-0.04
Other crops	-0.35	-0.005	-0.35	0.41
Non-crop sectors	-0.08	-0.08	-0.16	-0.20
Total midland GDP	0.06	0.02	0.08	0.11
Maize	-5.16	0.09	-5.08	0.20
Wheat	0.19	2.65	2.84	-0.04
Other crops	-0.26	0.01	-0.25	0.35
Non-crop sectors	0.23	0.10	0.33	0.07

Table 3: Impact on factor demand and income by agro-ecological zone in 2030

	Change from baseline level in 2030 (%)									**Change over the Scenario 3 (%)**		
	Simulation 1			**Simulation 2**			**Simulation 3**			**Simulation 4**		
Factor demand	Labour	Land	Capital	Labour	Land	Capital	Labour	Land	Capital	Labour	Land	Capital
Highland	**0.01**	**0.00**	**-0.12**	**0.00**	**0.00**	**-0.04**	**0.01**	**0.00**	**-0.16**	**-0.01**	**0.00**	**0.06**
Maize	-3.85	-3.24	-3.62	0.25	0.18	0.16	-3.61	-3.06	-3.45	1.25	0.35	1.86
Wheat	1.76	2.42	0.64	0.58	0.51	0.32	2.34	2.93	0.96	2.31	1.40	2.56
Other crops	0.06	0.71	-0.40	-0.02	-0.08	0.01	0.03	0.63	-0.39	0.70	-0.18	1.48
Non-crop	0.09	0.00	-0.07	-0.01	0.00	-0.04	0.07	0.00	-0.11	-0.19	0.00	-0.05
Lowland	**-0.01**	**0.00**	**-0.07**	**-0.01**	**0.00**	**-0.04**	**-0.02**	**0.00**	**-0.11**	**-0.01**	**0.00**	**-0.10**
Maize	-6.27	-5.30	-1.15	0.05	-0.01	0.01	-6.22	-5.31	-1.14	0.59	-0.47	0.29
Wheat	-0.65	0.38	0.00	-0.84	-0.90	0.00	-1.49	-0.52	-0.01	0.72	-0.34	0.01
Other crops	-1.14	0.02	-1.00	0.02	0.00	0.06	-1.12	0.02	-0.94	1.18	0.002	1.69
Non-crop	0.00		-0.06	-0.03		-0.04	-0.02		-0.10	-0.19		-0.11
Midland	**0.01**	**0.00**	**0.03**	**0.00**	**0.00**	**0.03**	**0.02**	**0.00**	**0.06**	**0.00**	**0.00**	**-0.03**
Maize	-10.97	-10.05	-3.00	0.13	0.09	0.03	-10.84	-9.96	-2.97	0.97	-0.17	0.55
Wheat	-0.49	0.53	-0.04	-0.39	-0.44	-0.02	-0.88	0.10	-0.05	0.81	-0.32	0.08
Other crops	-0.96	0.06	-0.94	0.03	0.00	0.04	-0.92	0.06	-0.90	0.38	-0.05	1.60
Non-crop	0.05	0.00	0.05	0.00	0.00	0.03	0.05	0.00	0.08	-0.13	0.00	-0.06
Factor demand (national)	**0.01**	**0.00**	**-0.06**	**0.00**	**0.00**	**-0.01**	**0.01**	**0.00**	**-0.07**	**-0.004**	**0.00**	**0.01**
Factor Income												
Highland (all)	0.008	-0.457	0.038	0.027	0.085	0.022	0.036	-0.373	0.061	-0.005	0.707	-0.169
Lowland (all)	0.061	-0.483	0.062	0.037	0.086	0.017	0.098	-0.398	0.079	0.027	0.727	-0.229
Midland (all)	0.118	-0.490	0.030	0.063	0.078	0.020	0.182	-0.413	0.051	0.024	0.721	-0.156
All economy	**0.043**	**-0.476**	**0.021**	**0.044**	**0.083**	**0.022**	**0.087**	**-0.393**	**0.043**	**0.008**	**0.710**	**-0.167**

Note: There is excess supply of skilled labour. Land is assumed to be fully utilized. New capital is created through investment process in the long run.

Table 4: Impact on household food and non-food consumption in 2030

	Simulation 1 (% change from baseline level)						Simulation 2 (% change from baseline level)					
	Maize	**Wheat**	**Processed food**	**Other food**	**Non-food**	**Total real consumption**	**Maize**	**Wheat**	**Processed food**	**Other food**	**Non-food**	**Total real consumption budget**
Highland (all)	**0.70**	**0.06**	**0.12**	**0.11**	**0.08**	**0.13**	**0.02**	**0.43**	**0.05**	**0.02**	**0.02**	**0.03**
hghl-rur1	0.72	-0.01	0.02	0.03	-0.07	-0.15	0.04	0.47	0.09	0.04	0.07	0.07
hghl-rur2	0.73	0.01	0.04	0.04	-0.06	-0.10	0.03	0.46	0.08	0.04	0.07	0.06
hghl-rur3	0.74	0.03	0.06	0.07	-0.02	-0.05	0.03	0.45	0.07	0.03	0.06	0.05
hghl-rur4	0.77	0.06	0.10	0.10	0.02	0.03	0.02	0.44	0.07	0.02	0.04	0.04
hghl-rur5	0.77	0.09	0.12	0.13	0.05	0.14	0.01	0.41	0.05	0.01	0.03	0.03
hghl-urb1	0.64	0.26	0.32	0.23	0.29	0.23	0.00	0.47	0.05	0.00	0.02	0.02
hghl-urb2	0.57	0.22	0.27	0.19	0.26	0.25	0.00	0.42	0.05	0.01	0.03	0.02
hghl-urb3	0.49	0.15	0.19	0.14	0.16	0.22	0.00	0.39	0.05	0.01	0.03	0.02
hghl-urb4	0.51	0.16	0.20	0.15	0.16	0.23	0.00	0.40	0.04	0.00	0.02	0.02
hghl-urb5	0.48	0.14	0.18	0.15	0.13	0.25	0.00	0.37	0.03	0.00	0.01	0.01
Lowland (all)	**1.05**	**0.31**	**0.32**	**0.35**	**0.27**	**0.23**	**0.02**	**0.47**	**0.06**	**0.02**	**0.03**	**0.03**
lowl-rur1	1.10	0.35	0.39	0.40	0.42	0.22	0.02	0.49	0.07	0.03	0.05	0.04
lowl-rur2	1.07	0.34	0.38	0.39	0.40	0.22	0.02	0.48	0.06	0.02	0.04	0.04
lowl-rur3	1.05	0.31	0.35	0.37	0.35	0.22	0.01	0.47	0.06	0.02	0.04	0.03
lowl-rur4	0.99	0.28	0.32	0.33	0.30	0.24	0.01	0.45	0.05	0.01	0.03	0.02
lowl-rur5	0.95	0.25	0.29	0.30	0.25	0.24	0.01	0.45	0.06	0.01	0.03	0.03
lowl-urb1	0.91	0.20	0.24	0.24	0.20	0.23	0.03	0.47	0.08	0.04	0.06	0.04
lowl-urb2	0.87	0.17	0.21	0.21	0.16	0.24	0.02	0.44	0.06	0.02	0.04	0.03
lowl-urb3	0.91	0.20	0.24	0.24	0.19	0.26	0.01	0.44	0.05	0.01	0.03	0.02
lowl-urb4	0.89	0.19	0.23	0.24	0.18	0.25	0.02	0.44	0.06	0.02	0.04	0.03
lowl-urb5	0.86	0.16	0.20	0.21	0.13	0.26	0.01	0.43	0.05	0.01	0.02	0.02
Midland (all)	**0.76**	**0.23**	**0.26**	**0.25**	**0.22**	**0.23**	**0.02**	**0.46**	**0.07**	**0.02**	**0.04**	**0.04**
midl-rur1	0.96	0.24	0.28	0.28	0.25	0.07	0.03	0.48	0.08	0.03	0.06	0.05
midl-rur2	0.96	0.23	0.27	0.28	0.24	0.10	0.03	0.48	0.08	0.03	0.05	0.05
midl-rur3	0.63	0.26	0.31	0.25	0.31	0.14	0.02	0.48	0.08	0.02	0.06	0.05
midl-rur4	0.59	0.24	0.29	0.23	0.28	0.19	0.01	0.45	0.07	0.02	0.05	0.05
midl-rur5	0.55	0.21	0.25	0.21	0.22	0.27	0.01	0.43	0.07	0.02	0.05	0.04
midl-urb1	0.89	0.21	0.24	0.24	0.19	0.26	0.02	0.44	0.06	0.02	0.04	0.03
midl-urb2	0.84	0.16	0.20	0.21	0.14	0.24	0.02	0.44	0.06	0.02	0.04	0.03
midl-urb3	0.87	0.17	0.21	0.22	0.15	0.26	0.02	0.45	0.07	0.03	0.04	0.04
midl-urb4	0.88	0.19	0.23	0.24	0.17	0.28	0.02	0.44	0.06	0.02	0.04	0.04
midl-urb5	0.91	0.21	0.25	0.27	0.18	0.30	0.02	0.45	0.07	0.02	0.04	0.04
Rural (all)	0.77	0.13	0.17	0.16	0.10	0.10	0.02	0.46	0.07	0.02	0.04	0.04
Urban (all)	0.60	0.16	0.20	0.18	0.14	0.26	0.004	0.40	0.04	0.004	0.01	0.02
National	**0.74**	**0.14**	**0.18**	**0.17**	**0.13**	**0.17**	**0.02**	**0.45**	**0.06**	**0.02**	**0.03**	**0.03**

Table 4 (continued): Impact on household food and non-food consumption in 2030

	Simulation 3 (% change from baseline level)						Simulation 4 (% change from Scenario 3)					
	Maize	Wheat	Processed food	Other food	Non-food	Total real consumption budget	Maize	Wheat	Processed food	Other food	Non-food	Total real consu-mption budget
Highland (all)	**0.72**	**0.49**	**0.17**	**0.13**	**0.10**	**0.16**	**0.56**	**0.75**	**0.36**	**0.54**	**0.26**	**0.37**
hghl-rur1	0.76	0.46	0.11	0.07	0.00	-0.08	0.90	1.12	0.90	1.15	1.11	0.90
hghl-rur2	0.76	0.47	0.12	0.08	0.01	-0.04	0.81	1.01	0.79	1.01	0.95	0.80
hghl-rur3	0.77	0.48	0.13	0.10	0.03	0.01	0.72	0.91	0.69	0.89	0.81	0.71
hghl-rur4	0.79	0.51	0.16	0.13	0.06	0.07	0.61	0.77	0.54	0.73	0.62	0.58
hghl-rur5	0.77	0.51	0.17	0.14	0.08	0.17	0.40	0.52	0.30	0.48	0.30	0.37
hghl-urb1	0.65	0.74	0.37	0.23	0.31	0.25	0.28	0.59	0.35	0.38	0.36	0.21
hghl-urb2	0.57	0.65	0.32	0.19	0.29	0.27	0.22	0.46	0.23	0.29	0.24	0.17
hghl-urb3	0.50	0.55	0.24	0.15	0.18	0.24	0.20	0.42	0.21	0.27	0.22	0.23
hghl-urb4	0.51	0.56	0.25	0.16	0.19	0.25	0.20	0.42	0.21	0.26	0.21	0.21
hghl-urb5	0.48	0.52	0.21	0.15	0.13	0.26	0.13	0.30	0.09	0.13	0.04	0.16
Lowland (all)	**1.07**	**0.78**	**0.38**	**0.37**	**0.30**	**0.26**	**0.50**	**0.65**	**0.36**	**0.46**	**0.32**	**0.36**
lowl-rur1	1.12	0.85	0.47	0.43	0.48	0.26	0.57	0.74	0.48	0.52	0.55	0.46
lowl-rur2	1.09	0.82	0.45	0.41	0.45	0.25	0.55	0.70	0.45	0.53	0.51	0.42
lowl-rur3	1.07	0.79	0.42	0.38	0.39	0.25	0.50	0.64	0.39	0.42	0.42	0.41
lowl-rur4	1.00	0.74	0.37	0.34	0.33	0.27	0.41	0.54	0.29	0.38	0.29	0.30
lowl-rur5	0.97	0.70	0.34	0.31	0.28	0.27	0.41	0.54	0.29	0.42	0.29	0.31
lowl-urb1	0.94	0.67	0.32	0.27	0.26	0.27	0.56	0.71	0.48	0.70	0.53	0.45
lowl-urb2	0.89	0.62	0.28	0.24	0.21	0.28	0.41	0.54	0.31	0.52	0.32	0.34
lowl-urb3	0.92	0.65	0.30	0.26	0.22	0.28	0.34	0.45	0.21	0.42	0.18	0.22
lowl-urb4	0.91	0.64	0.29	0.26	0.22	0.27	0.39	0.51	0.28	0.46	0.27	0.30
lowl-urb5	0.87	0.60	0.25	0.22	0.15	0.28	0.31	0.42	0.18	0.36	0.15	0.26
Midland (all)	**0.78**	**0.69**	**0.33**	**0.27**	**0.26**	**0.27**	**0.46**	**0.73**	**0.38**	**0.49**	**0.33**	**0.38**
midl-rur1	0.99	0.72	0.35	0.32	0.30	0.12	0.71	0.90	0.66	0.91	0.75	0.61
midl-rur2	0.99	0.71	0.35	0.32	0.29	0.15	0.68	0.86	0.62	0.82	0.68	0.58
midl-rur3	0.64	0.74	0.39	0.27	0.37	0.19	0.42	0.84	0.63	0.56	0.75	0.53
midl-rur4	0.60	0.70	0.36	0.26	0.34	0.24	0.33	0.68	0.47	0.43	0.55	0.45
midl-rur5	0.56	0.64	0.32	0.22	0.27	0.31	0.23	0.49	0.27	0.28	0.28	0.32
midl-urb1	0.91	0.65	0.30	0.26	0.23	0.29	0.40	0.53	0.30	0.61	0.29	0.28
midl-urb2	0.86	0.60	0.26	0.23	0.18	0.27	0.39	0.51	0.28	0.57	0.28	0.29
midl-urb3	0.89	0.63	0.28	0.25	0.19	0.30	0.37	0.49	0.25	0.52	0.23	0.28
midl-urb4	0.90	0.64	0.29	0.26	0.20	0.31	0.34	0.45	0.22	0.45	0.19	0.26
midl-urb5	0.93	0.66	0.31	0.29	0.22	0.34	0.31	0.41	0.17	0.37	0.14	0.25
Rural (all)	0.79	0.59	0.24	0.18	0.14	0.14	0.58	0.80	0.51	0.66	0.51	0.52
Urban (all)	0.60	0.56	0.24	0.18	0.15	0.28	0.19	0.35	0.13	0.21	0.08	0.19
National	**0.76**	**0.59**	**0.24**	**0.19**	**0.16**	**0.2**	**0.52**	**0.74**	**0.37**	**0.53**	**0.30**	**0.38**

Appendix-2

Table A1: Commodities produced in different regions

Agriculture		**Services**	
Maize	(highland, lowland, Midland)	Water	(highland, midland)
Wheat	(highland, lowland, Midland)	Electricity	(highland, midland)
Rice	(highland, midland)	Construction	(highland, lowland, midland)
Roots	(lowland, midland)	Trade	(highland, lowland, midland)
Pulses	(highland, lowland, Midland)	Hotel	(highland, lowland, midland)
Oilseeds	(highland, midland)	Transports	(highland, lowland, midland)
Fruits	(lowland, midland)	Public services	(highland, lowland, midland)
Vegetables	(highland, lowland, midland)	Other services	(highland, lowland, midland)
Cash crops	(highland, lowland, Midland)		
Other crops	(highland, lowland, midland)		
Livestock	(highland, lowland, lidland)		
Other agriculture	(highland, lowland, midland)		
Manufacturing			
Processed food	(highland, lowland, midland)		
Petrol prods.	(highland, midland)		
Chemicals	(highland, lowland, Midland)		
Engineering prod.	(highland, midland)		
Other manufacturing	(highland, lowland, midland)		

Table A2: Structure of the Kenya economy

	National	Highland	Lowland	Midland
Population (millions)	**37.75**	**16.70**	**4.73**	**16.32**
GDP per capita (KSH million)	**42469**	**55612**	**18133**	**36074**
Share of national GDP (%)		**58**	**5**	**37**
Share of regional GDP (%)	**100**			
Agriculture	24.0	69.6	5.5	24.9
Maize	13.0	78.7	0.9	20.4
Wheat	2.3	80.1	2.0	17.9
Other crops	62.0	83.4	0.5	16.0
Livestock	23.0	24.7	22.5	52.8
Non-agriculture	76.0	54.2	5.3	40.5
of which, food processing		64.3	3.8	31.9
Share of cultivated land (%)		**82**	**1**	**17**
Share of regional cultivated land (%)				
Maize		78.7	0.9	20.4
Wheat		80.1	2.0	17.9
Other food crops		81.9	0.7	17.4
Export-oriented crops (e.g. cash crops, etc)		85.1	0.3	14.5
Share of maize and wheat in consumption basket (%)				
Total food (incl. livestock & processed food)				
Rural households		56.6	76.0	57.8
Urban households		35.9	51.6	41.4
Maize				
Rural households		4.2	4.8	5.4
Urban households		1.1	0.6	1.3
Wheat				
Rural households		0.1	0.1	0.1
Urban households		0.0	0.0	0.0
Livestock				
Rural households		8.3	29.0	11.3
Urban households		7.4	8.1	6.2
Processed food				
Rural households		21.2	25.3	22.1
Urban households		16.3	28.5	21.2

Source: Kenya Social Accounting Matrix 2007

Table A3: Structure of supply and demands of the Kenya economy

	% of total supply			% of total supply				
	Imports	Production	Total	Exports	Intermediate demand	Household consumption	Investment	Total
Maize	4.25	95.75	100	0.18	51.71	48.11	0.00	100
Wheat	34.43	65.57	100	1.23	95.48	3.29	0.00	100
Rice	50.21	49.79	100	0.35	36.80	62.85	0.00	100
Roots	0.01	99.99	100	0.00	5.97	94.03	0.00	100
Pulses	4.56	95.44	100	2.97	5.93	91.10	0.00	100
Oilseeds	41.34	58.66	100	5.65	2.17	92.17	0.00	100
Fruits	0.87	99.13	100	1.20	22.19	76.60	0.00	100
Vegetables	0.22	99.78	100	21.00	8.33	70.67	0.00	100
Other crop	4.08	95.92	100	71.39	18.58	10.03	0.00	100
Livestock	0.13	99.87	100	0.28	23.69	76.04	0.00	100
Other Ag	1.50	98.50	100	19.97	67.59	9.97	2.47	100
Processed food	18.98	81.02	100	2.98	17.86	79.15	0.00	100
Other manufacturing	43.59	56.41	100	9.82	58.50	27.57	4.10	100
Services	5.23	94.77	100	11.24	32.77	39.00	16.98	100

Source: Kenya Social Accounting Matrix 2007

Table A4: Distribution of income in the national economy and sources of household income

	Distribution of income (% of total national income)					Sources of income (% of total income of the household)				
	Income	Labour	Land	Livestock	Capital	Labour	Land	Livestock	Capital	Total
Total highland	67.38	54.39	82.21	26.06	77.52	33.41	15.36	0.87	50.36	100
Total lowland	4.29	6.55	0.68	21.98	2.29	63.16	1.98	11.49	23.37	100
Total midland	28.32	39.06	17.11	51.96	20.18	57.08	7.61	4.12	31.19	100
Total	100	100	100	100	100	38.81	13.41	1.94	45.85	

Source: Kenya Social Accounting Matrix 2007

Table A5: Share of factor inputs by food and non-food activities (%)

	Maize	**Wheat**	**Rice**	**Other food**	**Non-food**	**Total**
Labour-highland	2.59	0.34	0.05	7.37	89.66	100
Labour-lowland	3.84	0.50	0.07	10.91	84.69	100
Labour-midland	6.89	0.90	0.12	19.60	72.49	100
Total Labour	**3.69**	**0.48**	**0.07**	**10.50**	**85.26**	**100**
Land-highland	16.11	3.21	0.42	50.81	29.45	100
Land-lowland	23.00	9.73	0.00	53.18	14.09	100
Land-midland	20.10	3.45	0.39	51.95	24.12	100
Total Land	**16.84**	**3.30**	**0.41**	**51.02**	**28.43**	**100**
Cap-Ag-highland	11.36	2.41	0.56	46.90	38.79	100
Cap-Ag-lowland	3.66	1.65	0.00	9.74	84.95	100
Cap-Ag-midland	5.10	0.93	0.19	15.53	78.25	100
Total Ag. Capital	**8.94**	**1.86**	**0.41**	**34.83**	**53.96**	**100**
Cap-Non Ag					**100**	**100**

Source: Kenya Social Accounting Matrix 2007

Table A6: Baseline maize and wheat yields, trend factor productivity growth and yield gain from promising varieties agro-ecological zone

Baseline scenario	Yield in the base year (t/ha)[1]	Trend productivity rates in the baseline (%)[2]					Varietal attributes [3]	Yield gain brought by promising varieties[3]	
	2007	2008-2010	2010-2015	2015-2020	2020-2025	2025-2030		Gain (%)	Gain (kg/ha)
Maize									
Highland	2.035	3.5	3.4	2.8	2.0	2.1	HY	5.00	89.0
Lowland	1.740	3.5	3.4	2.8	2.0	2.1	HY & DT	4.51	72.4
Midland	1.835	3.5	3.4	2.8	2.0	2.1	HY & DT	4.28	65.1
Wheat									
Highland	3.773	6.2	4.2	3.9	3.6	3.6	HY	3.02	96.7
Lowland	1.247	6.2	4.2	3.9	3.6	3.6	HY & DT	2.69	57.2
Midland	2.503	6.2	4.2	3.9	3.6	3.6	HY & DT	2.92	30.9

1. Calculated using crop model data
2. Based on IMPACT studies: trends in productivity growth driven by technological and agronomic improvements.
3. For maize, based on experimental data and for wheat, based on DSSAT simulations.