Potential Economic Impact of a "Green Revolution" in Sub-Saharan Africa: a CGE analysis

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Abstract

Africa, more specifically Sub Saharan Africa (SSA), largely missed out on the green revolution and hence is considered to have a large potential for a green revolution in the near future. Given this background, in this paper a global CGE Model is used to analyze the economy-wide effects of a potential 'green revolution' in SSA. Following many studies in the literature a potential green revolution is modelled as an increase in TFP, on the other hand, the uniqueness of this study is to introduce the observed and desired yield changes and let the model determine the required TFP change to attain these yield levels. Further, a stochastic yield change is introduced as a shock to the CGE model by using a Gaussian Quadrature approach. This way, instead of presenting only one point for a probable Green revolution one can analyse the effect of a green revolution under a whole possible set of yield changes.

The preliminary results suggests that the effect on production is significant in all regions, even more so the wheat production in South African Development Community (DC) region and plant fibre production in Central Africa regions. The impact on international trade is highest for Eastern Africa while the highest GDP and welfare gain is observed in South African DC countries.

Disclaimer: The views expressed are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

1. *Introduction*

In 1961 the world was feeding 3.5 billion people by cultivating 13.7 million km² of land, half a century later, even though world population doubled, cultivated land only expanded 12% thanks to the development of higher-yielding cereal seeds and an exceptional expansion in the use of irrigation, fertilisers and pesticides (Fuglie et al., 2012). This big jump in farm productivity was especially prominent during the 60s in Asia, Eastern Europe and Latin America, which William Gaud, a former director of USAID[1], referred to as a "green revolution" (Yapa, 1993).

But Africa, mainly Sub Saharan Africa (SSA), largely missed out on the green revolution. Sachs (2008) points out that the continent is long overdue for an agricultural boon like that lifted other regions such as Asia, where cereal yields jumped from 1 tonne a hectare in 1960 to more than 3 tonnes in 2011, while cereal yields in sub-Saharan countries rose to only 1.3 tonnes per hectare, up from 0.8 tonnes. This signals a scope for increasing productivity and economic growth in SSA, where the average GDP per capita is 2,334 current USD ppp[2], among the lowest in the world, (for comparison, USA's GDP per capita is around 60,000 USD ppp) and where one third of this GDP is contributed by agriculture (World Bank, 2012).

It is clear then, that an increase in agricultural productivity in SSA would favour a path to prosperity. In fact, 80% of SSA households live in rural areas and 70% of them depend on agriculture for their livelihood (Practical Action, 2005) and a green revolution in SSA is a real possibility; small projects in this region are already proving its effectiveness reaching three to five tons per hectare (Sachs, 2008). Malawi is a good example of this, where it has more than doubled its food output in just three years following a government program that subsidized farmers to access fertilizers and high-yield seeds. However, in most of SSA the yields are far below their potentials as the use of modern inputs (eg. fertilizers and high-yield seeds) is extremely low (Evenson et al. 2003).

The problem in SSA then, seems to rely on the lack of savings or access to credits and infrastructure (eg. roads, storage capacity and power). During the 80s and 90s, governments and donors where neglecting the agriculture sectors in SSA but since 2000s there is a

[1] United States Agency for international Development

[2] Ppp stands for purchasing parity power.

renewed commitment to agriculture centred on the Comprehensive Africa Agricultural Development Programme (CAADP) which is an Africa owned and led initiative with concrete objectives to boost agricultural productivity, targeting to achieve 6 percent agricultural annual growth and devote at least 10 percent of the government expenditure to agriculture. The European Union also has the commitment to support agricultural development in SSA, and sees it as a means to achieve the Millennium Development Goals with respect to the reduction of poverty and hunger (EC, 2007). Other organizations have also stepped forward, such as the Alliance for a Green Revolution in Africa[3].

Given this background, the main purpose of this paper is to analyse the economy-wide effects of a potential 'green revolution' in SSA, and the impact on its main trading partners. Given the past green revolution, it seems clear that a productivity-led agricultural growth is the best way to achieve it. In fact, according to World Bank 2007, the agricultural sector has the highest growth multiplier effects and is the most effective in reducing poverty. Tiffin and Irz (2006) proved that in most cases causality runs from agricultural growth to growth of overall economy, supporting the argument that agriculture has acted as the engine of growth. Moreover, it has been shown that a lack of agricultural productivity growth can severely constrain economy-wide growth (Irz and Roe 2005).

African agricultural development has been studied for a long time and even more since it failed to achieve an expected Green Revolution during the 70s, several studies have since focused and assessed the potential impact of a "Green Revolution" in Africa. Focusing on the most recent ones, Diao et al. (2007 & 2008) analyse the market opportunities for African agriculture and with the use of an economy-wide multimarket model conclude that the best way to promote growth in agriculture is with a productivity increase in food crops and livestock, but these need to be accompanied by an economy-wide growth and integrated regional markets to prevent a decline in the farmers' terms of trade. The study also concludes that in order to reduce poverty and have a rapid economic growth, an increase in productivity outside of agriculture is a necessary condition.

Breisinger et al. (2009) assesses the potential impact of a green revolution type of productivity-led growth in Ghana. Results from a computable general equilibrium model

[3] For further information visit the oficial webside of Allience for a Green Revolution in Africa: http://www.agra.org/

show that this type of green revolution would be strongly pro-poor and would provide substantial transfers to the rest of the economy, thus providing a strong argument to raise public expenditure on agriculture.

Similarly to these studies, this paper analyses the role of a potential green revolution in SSA's future development, a global computable general equilibrium model (GLOBE, McDonald et al., 2013) is used, where sub-Saharan Africa is represented with 5 regions and rest of the world with 15 regions. Based on this model, the green revolution is modelled as an increase in yields which is caused by a TFP increase, which is the common way to model it in the literature (eg. Diao et al. 2008).

On the other hand and by contrast to these studies, this paper is using yield changes as a proxy for the TFP change, the explicit relationship between yields and TFP is introduced in the model and allowed it to calculate the appropriate TFP change ratios that are consistent with the yield shocks introduced in the model. Further, instead of running static simulations, we used Gaussian Quadrature approach to span the whole statistical distribution of yield changes to obtain the statistical properties of the main economic variables.

The reminder of the paper is structured as follows. The second section presents the database used for the analysis. Then the modelling techniques used for the CGE model, the green revolution and the Gaussian quadrature are explained in the third section. Section four describes the baseline assumptions and scenarios performed. Results are presented in the fifth section while the last section concludes.

2. Data

The data used in this study is based on the GTAP database version 8 (Narayanan et al. 2012), it includes the dual reference years of 2004 and 2007 (in this case the 2007 reference year is used), all monetary values of the data are in million USD. The database covers 129 regions and 57 commodities. For computability, the database has been aggregated into 26 activities producing 26 commodities: ten agricultural, six food processing, nine industrial and one service sector. Seven out of ten agricultural activities are related to crop production activities (wheat, grains, fruits and vegetables, oil seeds, raw sugar, plant fibres and other crops) while the remaining three are livestock related sectors (cattle, pig and poultry and raw milk). Food processing sectors are modelled in detail to capture the linkages between agriculture and industry and consist of red meat, other meat, vegetable oils, dairy, sugar and other food production activities. Industrial sectors in the model are primary products, coal, oil, gas, petroleum, chemical and other industrial production activities. Regions were aggregated to 20 regions, where African countries and regions in the GTAP database are aggregated into seven regions according to the "Economic Partnership Agreement" classification. African regions in the model are as follows:

- West Africa: Cote d'Ivore, Ghana, Nigeria, Senegal , rest of the West Africa.
- Central Africa: Cameroon and Central Africa
- East African Development Community: Kenya, Tanzania, Uganda
- East and South Africa: South central Africa, Ethiopia, Madagascar, Malawi, Mauritus, Zambia, Zimbabwe, Rest of Eastern Africa
- South African Development Community (DC): Mozambique, Botswana, Namibia,
- South Africa: South Africa
- North Africa: Egypt, Morocco, Tunisia, Rest of North Africa

Other countries and regions in the GTAP data base are aggregated according to the standard classification by taking into account the major trading partners of the African regions: EU28, Rest of Europe, Middle East, USA, China, East Asia, South East Asia, South Asia, Rest of North America, South America, Former USSR, and Rest of the World.

In order to deduct the statistical properties of the distribution of annual yield changes in SSA between 1960 and 2012 the data used is from FAO (2014). First, crops in FAO database are aggregated to the GTAP crop production activities' level according to the mapping given in appendix Table A. 1. Second, the countries and regions are aggregated in the FAO database to match the model regions according to the mapping given in appendix Table A. 2.

After calculating the annual yield in percentage changes for each region and activity, interquartile range is used (i.e. the difference between the values of observations at the third and the first quartiles of data) to eliminate the outliers. The, the values of any observations outside the 1.5 times the interquartile range value are substituted with the value of the observation at the third quartile (if the outlier is larger than the third quartile) or the first quartile (if the outlier is smaller than the first quartile). Further, a 5 year moving average of the percentage changes are used to smooth the time series and to focus the analysis on the annual yield changes trends rather than the annual oscillations caused by various factors such as extreme climatic conditions or political conflicts. The mean and the standard deviation of the resulting annual yields percentage change are given in Table 1. The variance-covariance matrix for the change in yields of the crops within each region is given in appendix Table A. 3.

Table 1: Mean and Standard deviation (in parenthesis) of annual yield percentage changes

	Central	East	East&South	SADC	West	SSA
Grains	1.29	0.78	1.23	-0.34	1.11	0.82
	(1.96)	(2.79)	(3)	(5.7)	(2.61)	(3.49)
Wheat	0.44	1.34	2.17	1.64	0.03	1.12
	(4.81)	(4.7)	(2.38)	(8.2)	(7.4)	(5.89)
Plant Fibres	4.18	0.19	1.19	1.15	1.72	1.69
	(6.3)	(4.52)	(3.56)	(8.66)	(3.96)	(5.83)
Oil Seeds	0.59	2.30	-0.02	0.10	0.43	0.68
	(1.74)	(2.11)	(2.38)	(2.97)	(1.97)	(2.41)
Horticulture	0.40	0.62	1.08	1.98	0.97	1.01
	(1.02)	(1.2)	(1.04)	(2.33)	(1.7)	(1.62)
Raw Sugar	-0.70	0.98	0.31	0.86	1.00	0.49
	(3.88)	(3.5)	(1.53)	(2.34)	(2.86)	(2.99)
Other Crops	1.09	1.07	1.03	1.05	0.89	1.03
	(2.13)	(1.86)	(1.46)	(2.74)	(1.68)	(2.01)

Source: Authors' calculation from FAO (2014)
Note: Numbers in parenthesis are standard deviations and SADC refers to South Africa DC.

3. *Model*

3.1. GLOBE Model

The model used is a development of the GLOBE model (McDonald, Thierfelder and Walmsley, 2013). The GLOBE model is member of the multi-country, computable general equilibrium (CGE) models descendants from the approach described by Dervis et al. (1982). The model is a SAM-based CGE model, wherein the SAM serves to identify the agents in the economy and provides the database with which the model is calibrated. The implementation of this model, using the GAMS (General Algebraic Modelling System) software, is a direct descendant and extension of the single-country and multi-country CGE models developed in the late 1980s and early 1990s.

The within regional behavioural relationships are standard in this variant of the model; the activities are assumed to maximise profits using technology characterised by Constant

Elasticity of Substitution (CES) and/or Leontief production functions between aggregate primary inputs and aggregate intermediate inputs, with CES production functions over primary inputs and Leontief technology across intermediate inputs. The household maximises utility subject to preferences represented by a Stone-Geary utility function, i.e., a linear expenditure system, having first paid income taxes and having saved a fixed proportion of after tax income. The Armington assumption is used to represent trade behaviour. Domestic output is distributed between the domestic market and exports according to a two-stage Constant Elasticity of Transformation (CET) function with commodity and region specific elasticities of transformation.

Domestic demand is satisfied by composite commodities that are formed from domestic production sold domestically and composite imports modelled by a three stage CES function. At the bottom stage one composite import commodity is a CES aggregate of imports from different regions with the quantities imported from different regions being responsive to relative prices. The top stage defines a composite consumption commodity as a CES aggregate of a domestic commodity and a composite import commodity with the mix being determined by the relative prices. The elasticities of substitution are commodity and region specific. Hence the optimal ratios of imports to domestic commodities and exports to domestic commodities are determined by first order conditions based on relative prices.

We assume a neoclassical closure where saving rates are fixed and investment is savings driven. The exchange rate adjusts to keep current account balance fixed. On the other hand, factor markets are cleared by flexible wage rates under the assumption of full employment and full mobility with fixed supplies. Last, consumer price index is fixed as the numerairé.

3.2. Modelling Green Revolution

Green revolution is generally depicted as change in total factor productivity which is introduced to the CGE models as a shift in the top level production nest (Breisinger et al., 2009; Diao et al., 2008). However detailed TFP estimations are generally difficult to obtain, if not impossible, at regional and activity level. Estimations in the literature are either for the agriculture sector as a whole or for a limited number of specific crops. The only reliable and available information about the productivity in agricultural activities is yields. Thus, many use yields as a proxy for the TFP change and introduce the change in yields as TFP shocks by shifting the production functions. To count a few, Bosello & Zhang (2005), Ciscar et al.

(2009) and Fernandes et al. (2012) are the examples for the studies that follow this approach. However this approach is not precise in the sense that the relationship between land productivity and total factor productivity is not necessarily monotonic. Hence, we take a different and more accurate approach.

Consider the CES production function that is used to model the production activities in the GLOBE model.

$$Q = A\left(\sum_i \alpha_i \theta_i^{-\rho} X_i^{-\rho}\right)^{\frac{-1}{\rho}} \tag{1}$$

where A is the productivity parameter, X_i is the *i*th production factor, α_i is the share parameter and ρ is the substitution parameter, Then, the first order conditions for the cost minimization problem is given by:

$$w_i = PQ\frac{\alpha_i \theta_i^{-\rho} X_i^{-\rho-1}}{\sum_j \alpha_j \theta_j^{-\rho} X_j^{-\rho}} \tag{2}$$

Where P is price of the commodity and Q is the quantity produced. Equation (2) can be written for any two factors and dividing those two equations yields,

$$\frac{w_i}{w_k} = \frac{PQ\frac{\alpha_i \theta_i^{-\rho} X_i^{-\rho-1}}{\sum_j \alpha_j \theta_j^{-\rho} X_j^{-\rho}}}{PQ\frac{\alpha_k \theta_k^{-\rho} X_k^{-\rho-1}}{\sum_j \alpha_j \theta_j^{-\rho} X_j^{-\rho}}} = \frac{\alpha_i \theta_i^{-\rho} X_i^{-\rho-1}}{\alpha_k \theta_k^{-\rho} X_k^{-\rho-1}} \Rightarrow \alpha_k \theta_k^{-\rho} X_k^{-\rho} = \frac{w_k \alpha_i \theta_i^{-\rho} X_i^{-\rho-1}}{w_i} X_k \tag{3}$$

or

$$X_k^{-\rho} = \left(\frac{w_k \alpha_i \theta_i^{-\rho} X_i^{-\rho-1}}{w_i \alpha_k \theta_k^{-\rho}}\right)^{\frac{1}{-\rho-1}} \tag{4}$$

Substituting (3) in (1) would yield

$$Q = A\left(\sum_k \frac{w_k \alpha_i \theta_i^{-\rho} X_i^{-\rho-1}}{w_i} X_k\right)^{\frac{-1}{\rho}} = X_i A\left(\frac{\alpha_i \theta_i^{-\rho}}{w_i X_i}\right)^{\frac{-1}{\rho}} \left(\sum_k w_k X_k\right)^{\frac{-1}{\rho}} \tag{5}$$

Then yield of factor i, Y_i will be

$$Y_i = \frac{Q}{X_i} = A\left(\frac{\alpha_i \theta_i^{-\rho}}{w_i X_i}\right)^{\frac{-1}{\rho}} \left(\sum_k w_k X_k\right)^{\frac{-1}{\rho}} \tag{6}$$

Substituting (4) in (6) would yield

$$Y_i = A\left(\frac{\alpha_i \theta_i^{-\rho}}{w_i X_i}\right)^{\frac{-1}{\rho}} \left(\sum_k w_k \left(\frac{\alpha_i \theta_i^{-\rho}}{w_i}\right)^{\frac{1}{-\rho-1}} \left(\frac{w_k}{\alpha_k \theta_k^{-\rho}}\right)^{\frac{1}{-\rho-1}} \left(X_i\right)^{\frac{-\rho-1}{-\rho-1}}\right)^{\frac{-1}{\rho}}$$

Separating the parameters related to factor i in the summation would yield

$$= A\left(\frac{\alpha_i \theta_i^{-\rho}}{w_i X_i}\right)^{\frac{-1}{\rho}} \left(X_i \left(\frac{\alpha_i \theta_i^{-\rho}}{w_i}\right)^{\frac{1}{-\rho-1}} \sum_k w_k^{1+\frac{1}{-\rho-1}} \left(\frac{1}{\alpha_k \theta_k^{-\rho}}\right)^{\frac{1}{-\rho-1}}\right)^{\frac{-1}{\rho}}$$

This can be written as

$$A = Y_i \left(\frac{\alpha_i \theta_i^{-\rho}}{w_i}\right)^{\frac{1}{1+\rho}} \left(\sum_k \left(\alpha_k \theta_k^{-\rho} w_k^{\rho}\right)^{\frac{1}{1+\rho}}\right)^{\frac{1}{\rho}} \tag{7}$$

Equation (7) defines an explicit relationship between yield of any factor and TFP term of the CES production function. Hence, if yield changes are caused by TFP, then we can calculate the required shift in TFP that would result in the observed changes in yields. In other words, the observed changes in yield can be transformed to TFP shocks by using equation (7). However, the adjustment is a function of relative wages as well as the parameters of the production function. Therefore, equation (7) needs to be introduced to the model so that TFP shocks can be calculated simultaneously with the changes in wages.

In conclusion, by introducing equation (7) into the model, we are following the general assumption that green revolution implies an increase in TFP. However, instead of using yield changes as a proxy for TFP change, yields are shock in the model with the observed yield changes in the baseline and desired yield changes in the scenario.

3.3. Gaussian Quadrature

The potential of SSA to go through a green revolution is reported as evident in the literature[4] but the timing and magnitude of the impacts are unknown. Hence there is a lack of reliable estimations that link a green revolution to yield changes or any other productivity indicators. This calls for a stochastic approach in introducing the effects of a potential green revolution in a CGE model. In other words, the best available information on the probable changes in yields after a green revolution is the historical observations on yields. In order to facilitate this information we assume that yield change is a stochastic process where any observation at any point in time follows from a statistical distribution of which main parameters can be derived from the historical data. Once this information is obtained, then data from regions that already went through a green revolution is used in order to make an 'informed guess' about the probable change in the parameters of the statistical distribution of yield changes.

This approach allows us to derive the statistical distributions of the main economic variables, (e.g. the model outputs), which are a function of the distribution of the yield changes. This function is represented by the model itself and hence is quite complex and inevitably non-linear. Thus in order to derive the statistical properties of the main model outputs, we use the Gaussian Quadrature method, a well-established method in the literature (for a detailed discussion see Hermeling and Mennel (2008) and Hertel (2012)).

The Gaussian quadrature method is an approximation method for numerical integration. That is, weighted sum of function values at specific points in the domain of the function are used to approximate the value of the function (DeVuyst and Preckel, 1997). Gaussian quadrature method gives the weights and nodes in the following approximation:

$$\int_{\Omega} f(x)\,dx \cong \sum_{i=1}^{n} f(x_i)\,w_i \tag{8}$$

where $f(x)$ is a continuous function, x is the vector of independent variables, x_i is the vector of nodes selected in the domain of the integral, w_i are weights assigned to the value of the function at corresponding node and are called as quadrature, n is the minimum number of the nodes required for a good approximation. There are various formulas in the literature

[4] See the introduction for a review of few of these articles.

to calculate the weights and nodes efficiently, for example, Strauds' method is used widely in the CGE literature (Arndt, 1996). Strauds' method solves the following equation system to find nodes and weights.

$$\sum_{i=1}^{N} w_i \prod_{m=1}^{M} \left(x_i^m\right)^{l_m} = \int_a^b \prod_{m=1}^{M} \left(x_i^m\right)^{l_m} f\left(x\right)dx \quad s = 0,1,2....,d \text{ such that } \sum_{j=1}^{m} l_j \le d \qquad (9)$$

for all combinations of nonnegative integers l_m. d is called as the order of the quadrature. Many formulas for different quadrature orders and their arbitrary dimensions are developed in the literature, the most frequently used formulas are derived by Stroud (1957) and Liu (1997) for order 3 quadrature (Arndt, 1996) which are exact for orders smaller than 3 (Preckel et al., 2011).

Preckel et. al. (2011) propose an algorithm to extend the quadrature suggested by Straoud that samples the distribution function more broadly by taking into account the correlation between variables. They propose to use two copies of the Straud's quadrature and stretching one and shrinking the other to achieve the desired broadening of the sample while keeping the mean intact and redistributing the weights (or probabilities) so that the variance is maintained. Hence they introduce an expansion factor, denoted by α, a contraction factor, denoted by β, and a probability allocation factor, denoted by p. The resulting quadrature is

$$\left\{\left[pw^i, \alpha x^i\right]_{i=1}^{n}, \left[\left(1-p\right)w^i, \beta x^i\right]_{i=1}^{n}\right\} \qquad (10)$$

Preckel et al. (2011) shows that once the expansion factor, α, is chosen, the parameters β and p are given by

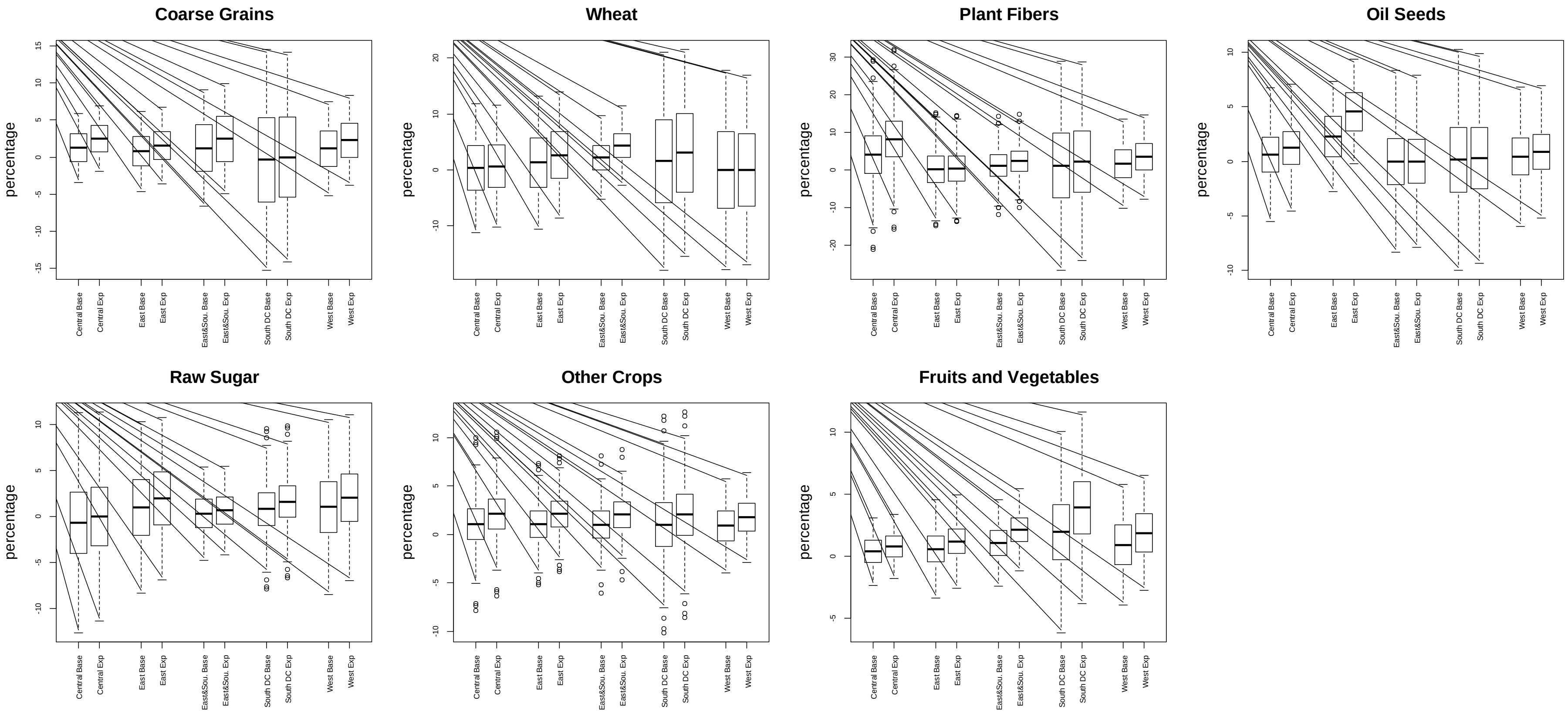
$$q = \frac{1-\kappa}{\alpha^4 - 2\alpha^2 + \kappa} \qquad \beta = \sqrt{\frac{\alpha^2 - \kappa}{\alpha^2 - 1}}$$

This approach is followed in this paper to capture the variation in the model results due to the yield changes. Accordingly, we assume that the percentage change in yields of each agricultural commodity follows from a symmetric distribution. The mean of the distribution is assumed to be equal to the observed historical mean in the base simulation. Then, we assume that the mean of the distribution will double after the green revolution as expected in the literature (Fuglie et al., 2012). Furthermore, the variation in the percentage change in yields is decreased to the 80 percent of the historical values since the risks associated with the climatic conditions, crop diseases etc… are expected to decline after the green revolution thanks to better infrastructure, utilization of modern inputs such as fertilizers or pesticides. Therefore, it is assumed that the mean of the yield distribution in percentage change are increasing together with a decline in variation. These assumptions are compatible with the observations in the literature about the green revolution that took place in the other parts of the world (Sachs, 2008).

We also assume that changes in the yields of different crops are not independent from each other within a country but they are independent across countries. The underlying reason is the fact that yields are linked to local factors such as climatic conditions, land quality, farmers' skills etc… and all commodities are dependent on the same factors within a country. For example, if the yield of one commodity is rising due to better irrigation infrastructure, other crops will also benefit from the same improvements and their yields are also likely to rise. To take this correlation into account we use the historical correlation between the annual price changes of the commodities as the variance covariance matrix.

Figure 1 below, shows the distribution of the yield changes obtained by the Gaussian Quadrature method. Yield change shocks are generally around 1 to 3 percent, however, the extreme points can go up as much as 30 percent (eg. Plant fibres in Central Africa) or down by -25 percent (eg. plant fibres in South African DC). The highest variation is observed in South African DC in all crops, but especially in grains, wheat and plant fibres. On the other hand, the variation in yield changes is lower in central and eastern regions. In general, variation in the yields of wheat and plant fibre is relatively higher in all regions. When we introduce the increase in expected values and decline in variance covariance for the experiment, the variations become smaller but the general pattern does not change.

Figure 1: Distribution of the Yield shocks introduced to the model



Source: Authors' calculations

4. *Results*

4.1. Production

Production of almost all crops increase on average as expected with the exception of slight declines in oilseeds and raw sugar production in East & South Africa. The average of yield shocks is negative for the former and very slow for the latter which implies negative or very small yield shocks. As these sectors in East & South Africa becomes relatively less competitive compared to the other production activities, their production declines.

The average increase in overall production is around 0.8 percent higher in the scenario compared to the baseline. Most significant increase is observed in the production of wheat in South African DC region and plant fibres production in Central Africa region with more than 3 percent increase. In general wheat and other crops turn out to be the most benefiting activities in all regions (former with the exception of West Africa and latter with the exception of East & South Africa) from the increases in yield change. Only exceptions are West Africa for wheat production and East & South Africa for other crops. .

Table 2: Average change in quantity of value added (million USD, percentage change relative to base)

	Central			East			East & South			SADC			West		
	Base	**Scen**	**%**	**Base**	**Scen**	**%**	**Base**	**Scen**	**%**	**Base**	**Scen**	**%**	**Base**	**Scen**	
Grain	11338.0	11358.54	***0.18***	30865.1	31149.0	***0.92***	40553.9	40825.3	***0.67***	14870.9	15244.7	***2.51***	86521.8	89411.7	***3***
Wheat	44.9	45.0	***0.30***	271.5	275.0	***1.28***	10434.8	10525.9	***0.87***	2199.1	2263.5	***2.93***	17.7	18.0	***1***
Veg&Fru.	28311.5	28375.3	***0.23***	31204.5	31525.4	***1.04***	53696.0	54166.2	***0.88***	32253.6	33347.3	***3.39***	449382.3	465397.8	***3***
Oilseeds	3829.2	3837.4	***0.21***	10845.8	10949.9	***0.96***	6897.4	6957.9	***0.88***	2071.2	2115.2	***2.13***	20308.2	20860.1	***2***
Raw Sugar	1107.7	1109.2	***0.13***	5683.2	5719.5	***0.64***	5091.3	5113.5	***0.44***	4776.1	4889.3	***2.37***	1625.0	1661.9	***2***
Plant Fibers	1262.5	1259.9	***-0.20***	778.9	784.3	***0.69***	3718.1	3733.4	***0.41***	664.6	690.2	***3.85***	22662.4	23255.8	***2***
Other Crops	5507.4	5511.8	***0.08***	31511.5	31947.4	***1.38***	28913.7	29122.6	***0.72***	8997.6	9602.9	***6.73***	42566.4	44543.7	***4***
Rest of Agriculture	7834.9	7833.8	***-0.01***	7653.0	7657.2	***0.06***	24679.3	24681.7	***0.01***	10734.6	10761.1	***0.25***	26839.1	26930.0	***0***
Food	5142.4	5144.1	***0.03***	12216.21	12230.7	***0.12***	8931.4	8938.8	***0.08***	12520.9	12545.8	***0.20***	7302.6	7328.8	***0***
Manufactu res	33820	338297	***0.03***	13443	13464	***0.16***	101165	101183.7	***0.02***	120881	120881.3	***0.00***	122571.9	122528.0	***-0***
Services	126917	1269728	***0.04***	111155	111274	***0.11***	334762	334984.3	***0.07***	951090	951722.7	***0.07***	401956.4	403066.7	***0***

Source: Model Results

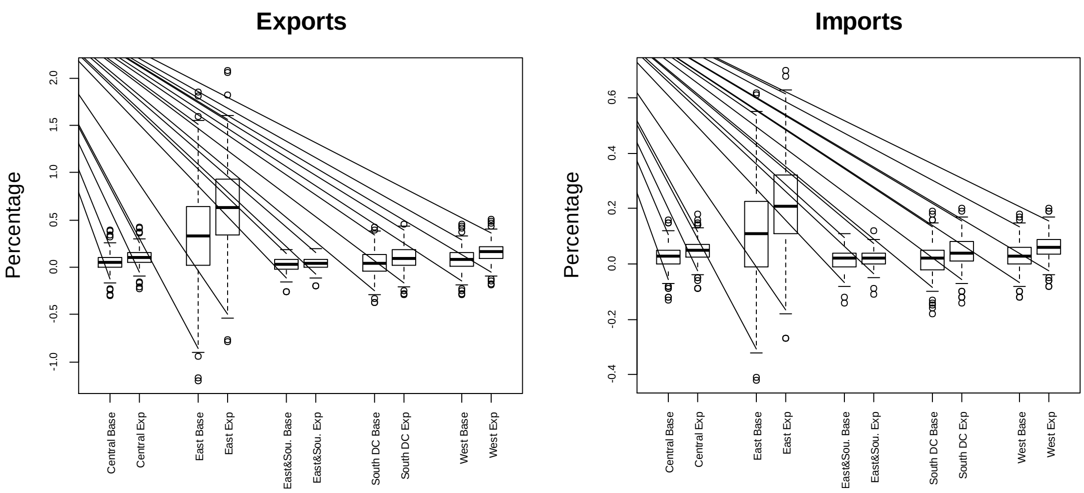
Note: Standard deviations in parenthesis, and SADC refers to South Africa DC.

The variation in production is significantly higher than the variation in the yield shocks implying the fact that the African economies cannot deal well with the extreme changes in yields. For example, the highest increase in production occurs for wheat in South African DC region with 3.6 percent but the standard deviation is also the highest with 19.5, implying a high risk of observing negative values. The second highest variation is observed for wheat and plant fibre production in Central Africa followed by South African DC region for plant fibers and grain production.

4.2. Trade

The effect of yield changes on international trade flows of the African regions is positive but small on average with changes in exports ranging from 0.02 percent to 0.3 percent and changes in imports from 0.02 percent to 0.1 percent relative to the baseline. However, the variation is relatively higher in East Africa, especially for exports where the change ranges between -1.3 percent and +2 percent.

Figure 2: Percentage change in total exports and imports relative to baseline



Source: Model Results

Decomposition of the African trade shows that different regions are affected differently from an increase in the yields. West and South Africa DC takes advantage of increasing yields and increase their agricultural exports to both rest of the world and to other African regions. However, Central Africa and East and South African DC countries' agricultural exports to other African regions decline slightly together with stagnating exports to the rest of the world.

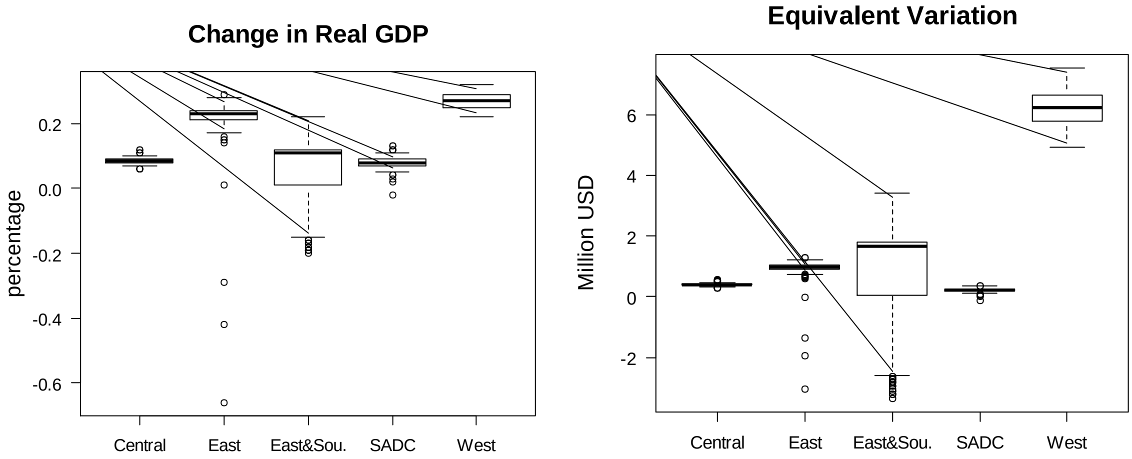
Table 3: Average change in exports relative to base with SSA and ROW (million USD).

	SSA			ROW		
	Baseline	Scenario	%	Baseline	Scenario	%
Central	**79.2**	**79.3**	0.10	**715.9**	**716.0**	0.02
Agriculture	5.4	5.4	-0.68	60.7	60.8	0.05
Manufactures	126.1	126.3	0.12	1029.0	1029.2	0.01
Services	100.7	100.8	0.16	2330.9	2331.7	0.03
East	**214.8**	**215.4**	0.31	**343.4**	**344.9**	0.43
Agriculture	61.9	62.3	0.72	205.3	208.6	1.60
Manufactures	320.7	321.5	0.25	221.5	221.7	0.06
Services	196.6	197.1	0.26	3322.6	3326.1	0.11
E&S Africa	**433.7**	**434.1**	0.10	**2169.3**	**2170.3**	0.04
Agriculture	112.7	112.6	-0.01	209.7	211.6	0.93
Manufactures	657.6	658.3	0.11	3294.2	3294.4	0.01
Services	286.3	286.9	0.19	4698.2	4700.7	0.05
SADC	**1508.5**	**1511.2**	0.18	**2427.9**	**2431.1**	0.13
Agriculture	115.8	119.1	2.80	211.2	219.6	3.99
Manufactures	2536.5	2538.9	0.10	3411.0	3410.7	-0.01
Services	426.3	427.1	0.18	9354.1	9356.9	0.03
West	**816.2**	**818.9**	0.33	**2434.7**	**2441.8**	0.29
Agriculture	101.5	103.4	1.94	374.2	393.8	5.25
Manufactures	1311.5	1314.8	0.25	3600.2	3598.9	-0.04
Services	303.2	304.0	0.28	5187.3	5194.6	0.14
Africa Total	**619.1**	**620.4**	0.21	**1628.5**	**1631.1**	0.16

4.3. GDP and Welfare

Both median value and other statistics of the change in GDP are diverse across regions. Average change is slightly above zero for Central, East&South and South African DC regions while it is slightly higher than 0.5 percent for East and West Africa regions, confirming that the latter gains more in terms of GDP due to the yield changes. On the other hand, the distribution of the difference in GDP change is relatively more disperse, spanning also negative values. In contrast, the other regions' distribution is concentrated around the median.

Figure 3: Change in GDP and Welfare relative to baseline



Source: Model Results

The difference in welfare, represented by the equivalent variation (EV) between the baseline and the scenario, are relatively small and follow the same pattern as the change in GDP. West African consumers gain significantly more compared to the other regions with a median difference around USD 6 Million and the distribution of the difference in EV spans only positive values. The second best regions in terms of welfare gain is East & South Africa region, with a higher median compared to rest of the regions, but in this case, the distribution is significantly more disperse and spans to include negative values.

Table 4: Average change in GDP and Welfare relative to base (million USD)

	GDP			Welfare		
	Baseline	Scenario	%	Baseline	Scenario	%
Central	592.5	592.8	0.05	-0.352	-0.137	61.08
East	544.3	545.9	0.29	0.800	2.109	163.63
E&S Africa	1761.7	1764.3	0.15	-0.493	1.048	312.58
SADC	3144.7	3149.9	0.17	-1.373	2.454	278.73
West	2516.5	2543.4	1.07	7.377	30.505	313.51

5. Conclusion

In this paper we presented the preliminary results of a global CGE analysis that aim to reveal the impact of the Green revolution on the African economies. Following many studies in the literature we model the green revolution as an increase in TFP but differently from them we introduce the observed and desired yield changes and let the model determine the required TFP change to attain these yield levels. Further, instead of running static scenarios we assume that yield changes are stochastic and have a statistical distribution and we introduce the whole distribution to the CGE model by using Gaussian Quadrature approach. In this way instead of presenting only one point for a probable Green revolution we can analyse the effect of green revolution under the whole possible set of yield changes.

The preliminary results suggests that the effect on production is significant in all regions but wheat production in South African DC region and plant fibre production in Central Africa regions are the most benefiting activities. Effect on international trade is higher in Eastern Africa while highest GDP and welfare gain is observed in South African DC countries.

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Appendix

Table A. 1. Mapping of FAO Crop Aggregates to Model Activities

Model Activity	FAO Crop Aggregate
Grains	Coarse Grains
Plant Fibers	Fibre Crops, Cereals nes
Fruits and Vegatables	Fuits, Vegetable and Melons, Roots and tubers
Oilcrops	Primary oil crops
Wheat	wheat
Sugar	Sugar Cane

Source: Authors' own classification

Table A. 2. Mapping of FAO Regions to Model Regions

Model Region	FAO Region
WAfrica	Benin, Burkina Faso, Cabo Verde, Côte d Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, Togo
CAfrica	Cameroon, Central African Republic, Chad, Congo, Democratic Republic of the Congo, Equatorial Guinea, Gabon, Sao Tome and Principe,
EAfrica	Burundi, Kenya, Rwanda, Saint Helena, Ascension and Tristan da Cunha, Uganda, United Republic of Tanzania
ESAfrica	Comoros, Djibouti, Eritrea, Ethiopia, Ethiopia PDR, Madagascar, Malawi, Mauritius, Réunion, Seychelles, Somalia, Sudan (former), Zambia, Zimbabwe
SAfricaDC	Angola, Botswana, Lesotho, Mozambique, Namibia, Swaziland

Source: Authors' own classification

Table A. 3: Variance covariance matrix

		Grains	Wheat	Fruit &Veg	Plant Fibres	Raw Sugar	Oil Seeds	Other Crops
WAfrica	Grains	6.82	-1.72	-1.21	2.46	-0.79	0.33	1.03
	Wheat	-1.72	54.78	0.27	-0.5	1.56	3.06	9.16
	Fruit&Veg	-1.21	0.27	2.91	-0.1	-0.71	-1.52	-0.17
	Plant Fibres	2.46	-0.5	-0.1	3.89	-1.02	2	1.1
	Raw Sugar	-0.79	1.56	-0.71	-1.02	8.22	0.51	1.41
	Oil Seeds	0.33	3.06	-1.52	2	0.51	15.71	3.37
	Other Crops	1.03	9.16	-0.17	1.1	1.41	3.37	2.84
CAfrica	Grains	3.87	-0.17	-0.02	0.66	1.72	5.8	1.96
	Wheat	-0.17	23.1	0.55	0.81	4.63	4.89	5.62
	Fruit&Veg	-0.02	0.55	1.04	0.39	-0.53	1.92	0.48
	Plant Fibres	0.66	0.81	0.39	3.02	2.33	1.61	1.47
	Raw Sugar	1.72	4.63	-0.53	2.33	15.03	9.54	5.22
	Oil Seeds	5.8	4.89	1.92	1.61	9.54	39.99	10.51
	Other Crops	1.96	5.62	0.48	1.47	5.22	10.51	4.55
EAfrica	Grains	7.81	2.05	0.91	-0.16	0.4	-0.05	1.88
	Wheat	2.05	22.1	2.31	1.21	0.85	1.64	5.34
	Fruit&Veg	0.91	2.31	1.45	0.9	-0.8	-0.71	0.84
	Plant Fibres	-0.16	1.21	0.9	4.55	-0.61	5.07	1.77
	Raw Sugar	0.4	0.85	-0.8	-0.61	12.27	3.87	2.62
	Oil Seeds	-0.05	1.64	-0.71	5.07	3.87	20.41	4.98
	Other Crops	1.88	5.34	0.84	1.77	2.62	4.98	3.47
ESAfrica	Grains	9.06	1.83	1.34	3.53	0.09	2.67	2.95
	Wheat	1.83	5.75	-0.01	0.08	-0.31	3.16	1.79
	Fruit&Veg	1.34	-0.01	1.11	0.65	0.38	-0.67	0.43
	Plant Fibres	3.53	0.08	0.65	5.68	0.53	2.54	1.99
	Raw Sugar	0.09	-0.31	0.38	0.53	2.36	-1.36	0.31
	Oil Seeds	2.67	3.16	-0.67	2.54	-1.36	12.7	3.53
	Other Crops	2.95	1.79	0.43	1.99	0.31	3.53	2.16
SAfricaDC	Grains	32.51	20.04	5.65	-0.25	-3.03	-13.08	6.9
	Wheat	20.04	67.28	4.68	6.01	-9.64	4.9	16.69
	Fruit&Veg	5.65	4.68	5.51	-2.46	-0.21	-0.74	2.18
	Plant Fibres	-0.25	6.01	-2.46	8.84	-2.86	7.8	2.66
	Raw Sugar	-3.03	-9.64	-0.21	-2.86	5.47	-3.24	-1.91
	Oil Seeds	-13.08	4.9	-0.74	7.8	-3.24	75.06	11.91
	Other Crops	6.9	16.69	2.18	2.66	-1.91	11.91	7.51

Source: Authors' calculation from FAO (2014)