IMPACT OF RAINFALL PATTERN ON CEREAL MARKET AND FOOD SECURITY IN SUDAN: STOCHASTIC APPROACH AND CGE MODEL

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Abstract

The paper aims at analysing the impact of the likely change in rainfall on food availability and access to food in Sudan. The empirical investigation is based on an integrated approach consisting of a stochastic method and CGE model. The former, related to the Monte Carlo analysis, provides the likely changes in rainfall patterns and their probability of occurrence based on historical data. These results are at the basis of the scenarios simulated in a standard CGE model augmented with a stochastic component. Achievements underline the negative impact on the two dimensions of food security taken into consideration, mainly due to a reduction in cereal supply, a marked cereal inflation pressure and income contraction; the greater negative effect on the poorest households; and a deterioration of the economic performance of the country. In this context, the paper stresses a strong interconnection among climate change and variability, poverty and food insecurity and thus the need for an integrated policy-making approach.

1. Introduction

The evidence from the literature agrees on three points: there is a high probability of significant changes in global climate (Ito et al., 2010; IPCC, 2007); the state of environment will continue to deteriorate if the right actions are not taken (Torres, 2008); and the relative impacts of climate change are greater in low-income countries (Tol, 2010). These latter are more vulnerable due to several factors, among which there are their location in tropical zones of the equatorial area, increasing temperatures that already affect production in sectors like agriculture, and their lower adaptation and institutional capacity.

The recently developed empirical investigations focus on specific aspects of the effect of climate change. The major topics concern the impact on agriculture and forestry, water resources, coastal zones, energy consumption, air quality and human health and welfare (Tol, 2010). Little attention is given to food security, particularly in Sub-Saharan Africa (Thompson et al., 2010). This paper addresses this topic, focusing on the impact of rainfall.

Changes in the precipitation patterns are one of the dimensions of climate change. This is of great importance in developing countries, where the rain-fed agriculture is still a dominant economic activity. Also in this respect, Sub-Saharan Africa shows a higher vulnerability compared to other developing areas. For example, in the continent, more than 95 per cent of the farmed land is rain-fed, whereas this is almost 90 per cent in Latin America, about 60 per cent in South Asia, 65 per cent in East Asia, and 75 per cent in the Near East and North Africa (Huho, 2011). This sector also constitutes the livelihood base for a vast majority of inhabitants and, for this reason, it plays a crucial role in food security (Wani et al., 2009).

The paper focuses on Sudan, one of the poorest countries in the world, and with more than a quarter of the population undernourished and 27 per cent of children under five malnourished (UNEP, 2007). Rainfall patterns make this country the driest and most at risk in Africa (Sassi, 2012). Indeed, precipitation is concentrated in four months only, and it is extremely variable over space, according to the ecological zones, and over time, with extreme weather events more frequent than normal.

The Sudanese agriculture is based on three farming systems, the traditional and mechanised rain-fed agriculture and the irrigated sector. According to the data provided by the General Directorate of Agricultural Planning and Economics of the Ministry of Agriculture and Forests, the former two sectors contribute to the production of the majority of staple foods, that is all millet and 75.93 per cent of sorghum. The Sudanese grain diet is completed by wheat, which instead is mainly grown with the irrigation system. As millet, sorghum and wheat are the major sources of food availability in the country, the paper limits climate-induced damage to these three crops. Moreover, since the paper takes into consideration crops with different degrees of dependence on rainfall, it is possible to indirectly evaluate the importance of irrigation. Nevertheless, rain-fed agriculture is also important for the economic access to food, as 70 per cent of the population depends on this sector for employment, income and, more generally, livelihood.

The above mentioned dimensions of the concept of food security introduced by the 1996 World Food Summit, i.e. food availability and access, are the specific focus of this paper. More precisely, the research questions of this paper are: according the rainfall predictions provided by the risk analysis, what is the likely change in millet, sorghum and wheat productivity and its probability of occurrence? Hence, what is the impact of such a change on food availability and household access to food and on the overall economy of the country? The answer is provided by the integration of two methodologies: a stochastic analysis and a CGE model.

In the literature, the economic impact of climate change and its manifestations has been assessed by either partial equilibrium or general equilibrium approaches. The former depict only part of an overall economy. On the contrary, general equilibrium models look at the economy as a whole system, where industries have an effect on each other or the rest of the economy; thus they provide an economy-wide analysis that may capture the links between the sector affected by the shock (in our case millet, sorghum and wheat) and the others (Zhai et al., 2009).

With the CGE model, this paper takes into consideration both of them, within an economy-wide approach. This analytical perspective is lacking in the investigation developed with respect to Sub-Saharan Africa. There are examples for Asia, such as the study of van der Mensbrugghe (2010).

More precisely, the paper uses the CGE model developed at the International Food Policy Research Institute (IFPRI) by Lofgren et al. (2002). The model is based on the 2004 social accounting matrix (SAM) for Sudan (Siddig, 2011), thereby considering the country prior to the separation. What is more, the CGE model is augmented with a stochastic component in order to simulate the effect of the likely changes in rainfall predicted by the risk analysis based on the Monte Carlo method. In this way, the paper does not simulate the “10 per cent shock” traditionally adopted by the empirical literature due to its easy interpretation. In fact, the stochastic method allows predicting a likely mean level of rainfall and the expected extreme values of an interval within which there is a 90 per cent probability for the true level of precipitations to be located. As a consequence, simulation results of the CGE model give a more accurate indication of the possible size of the effect of the likely rainfall changes.

The literature provides different approaches to modelling the macroeconomic impact of climate change. The standard approach is that, first, for alternative greenhouse gas scenarios, future climate scenarios and projections about precipitation patters are selected or obtained from existing General Circulation Models (GCM) for the country in question. Then, these results are used as input in the modeling of the impact of climate change on agriculture and food security, either through hydro-crop model or Ricardian model into the CGE model (see Mendelsohn et al., 1994; Zhai et al., 2009; Arndt et al., 2011). Nonetheless, our paper is aligned to the part of the literature that uses stochastic CGE models or CGE models with risk components, such as Harris and Robinson (2001) and Karaky and Arndt (2002). As a matter of fact, the adoption of the risk analysis allows facing another issue reported in the literature, that is the non-convergence on the direction and intensity of the future change in rainfall or, more generally, climate change (Nelson et al., 2010). Indeed, since the predictions of the models are often inaccurate and may significantly underestimate or overestimate current regional precipitation (Republic of the Sudan, 2003), we have decided to take into consideration the probability of occurrence of the change in the precipitation pattern.

The addition of a stochastic shock-parameter to the value-added function follows the approach adopted by a body of the literature. A similar methodology has been introduced by Harris and Robinson (2001) with the aim of simulating the general uncertainty in agriculture and/or uncertainty caused by ENSO (El Niño/Southern Oscillation) events in Mexico. However, in comparison to that analysis, this paper improves the definition of the stochastic shocks addressing the process of selection of the probability distribution functions in a more accurate way.

Another new element introduced by this paper is that it goes far beyond the traditional economy-wide general equilibrium analysis developed for Sudan, which only assesses the impact of trade liberalisation or exchange rate policies (Elbushra et al., 2010; Siddig, 2011; Siddig and Babiker, 2011).

The analysis developed here can contribute to better inform the current debate underway in Sudan on the strategy and the actions needed to tackle climate change, consequent to the signature of the international agreements and conventions such as the Kyoto Protocol and UNFCCC and the completion of its National Adaption Programme for Action (NAPA) (Zakieledeen, 2009).

The paper is structured as follows: section 2 introduces the methodology, articulated into the stochastic model and the CGE model; section 3 discusses achievements starting from the stochastic model, moving on to the scenarios simulated in the CGE model; section 4 concludes.

2. Methodology

2.1 Stochastic method

Risk analysis refers to the Monte Carlo method, a computer-based approach developed in the 1940s that uses statistical sampling techniques to obtain a probabilistic approximation to the solution of a mathematical equation model (Metropolis 1949; Hayse 2000).

It starts with the definition of the parametric model that explains the phenomena investigated and the estimation of its parameters. Then a probability distribution function is assigned to each of the input stochastic explanatory variables. The output from the model is calculated many times, randomly selecting a new value from the probability distributions for each of the input explanatory variables every time. The outputs from each run of the model are saved and a probability distribution for the output values is generated. This allows the probability of occurrence of any particular output value to be calculated. This paper makes reference to such values for the definition of the adopted scenarios in the baseline run.

The choice of the functional form of the parametric model, adopted to explain the effect of rainfall on yields of different crops, is based on a preliminary evaluation of outcomes, testing alternative simple (linear and log-linear) and more advanced functional forms. The paper refers to a generalised quadratic function, which results a reasonable approximation to the 'true' picture. This is defined as:

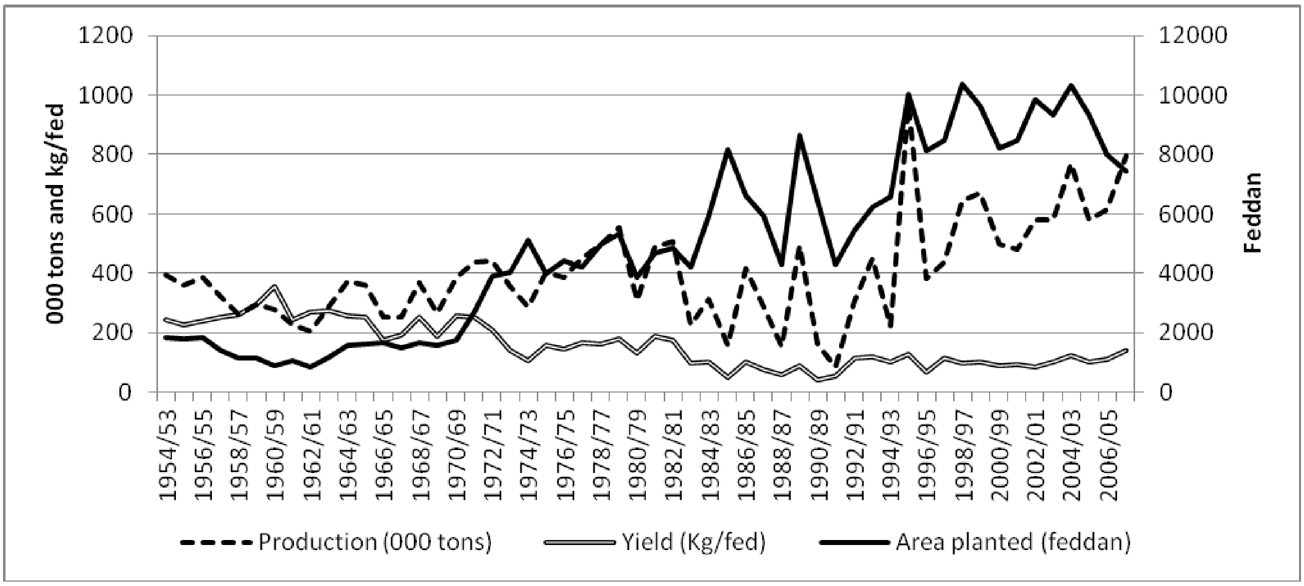
$$Q_{c.t} = \alpha RF_t + \beta RF_t^2 + \gamma T_t + \mu_t \qquad (1)$$

where Q_c represents productivity of crop c ($c = millet, sorghum\ and\ wheat$) at time t. Yield is expressed in kg per feddan (1 feddan = 1.038 acres or 0.42 ha), RF is the mm of rainfall, α β and γ are the parameters to be estimated, T is the time trend and μ is the random error term.

The rainfall effect on productivity is assumed to be positive but to diminish at the margin: excessive rainfall hampers agricultural output. For this reason, the sign of the square term of rainfall is expected to be negative (Eboh et al. 2012; Teklu et al. 1991).

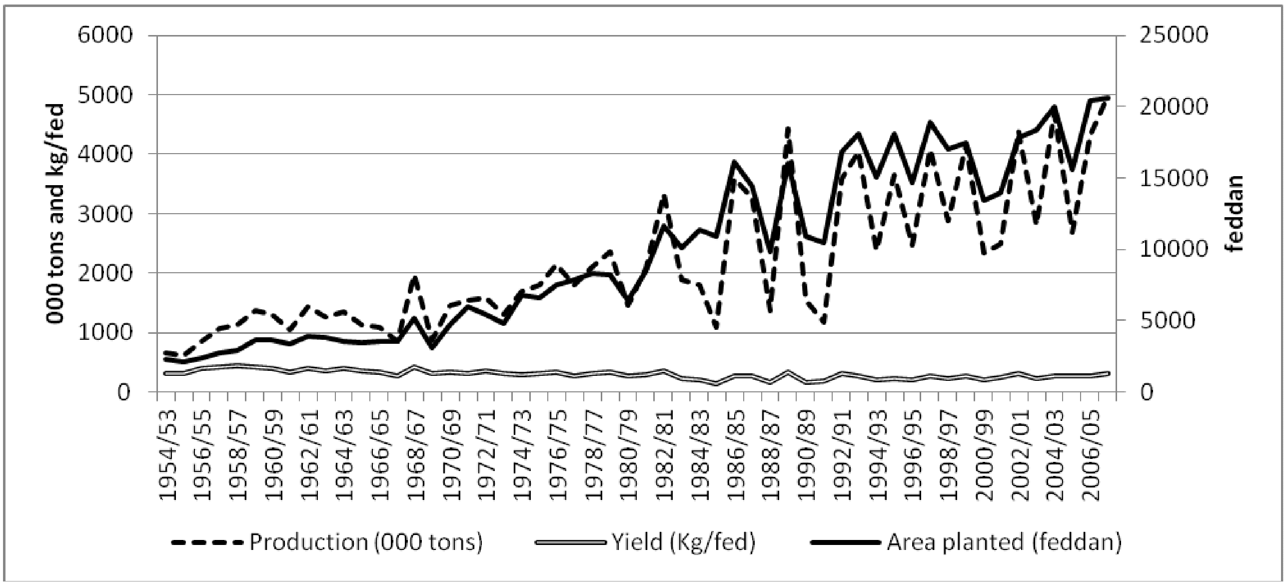
Turning to the impact variable, yield is preferred to the quantity produced because in Sudan the level of production is strongly dependent on the amount of land planted for the three crops taken into consideration, as shown in Figure 1, 2 and 3.

Figure 1 – Millet: Production (000 tons), yield (kg/fed) and area planted (feddan) (1954/53 – 2007/06)



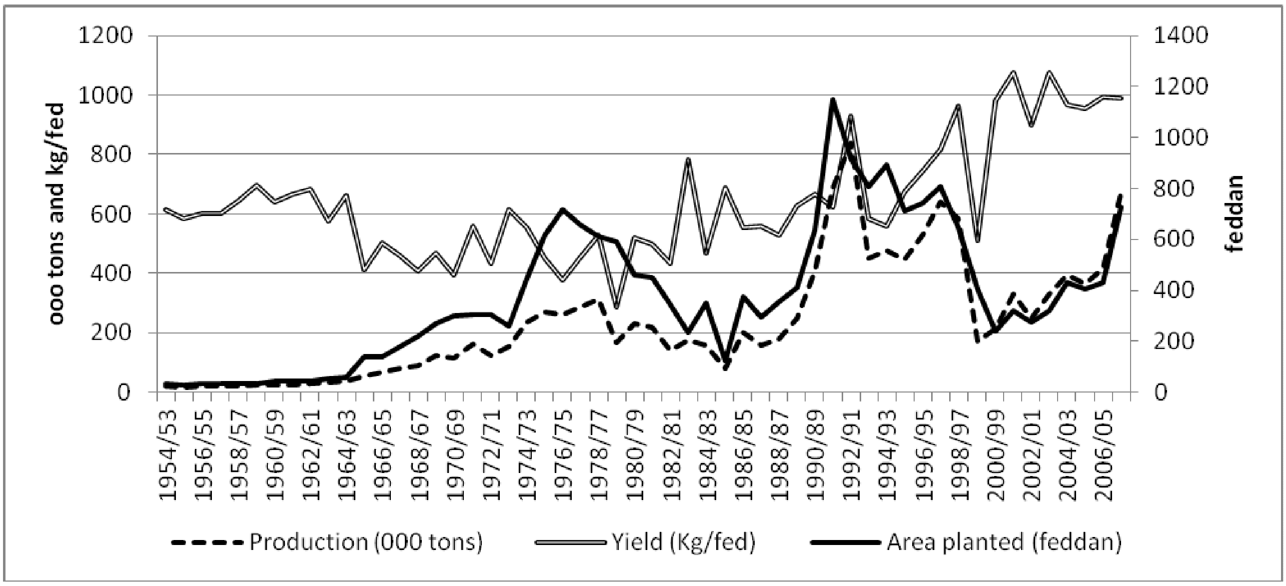
Source: authors' elaboration based on data provided by General Directorate of Agricultural Planning and Economics of the Ministry of Agriculture and Forests

Figure 2 – Sorghum: Production (000 tons), yield (kg/fed) and area planted (feddan) (1954/53 – 2007/06)



Source: authors' elaboration based on data provided by General Directorate of Agricultural Planning and Economics of the Ministry of Agriculture and Forests

Figure 3 – Wheat: Production (000 tons), yield (kg/fed) and area planted (feddan) (1954/53 – 2007/06)



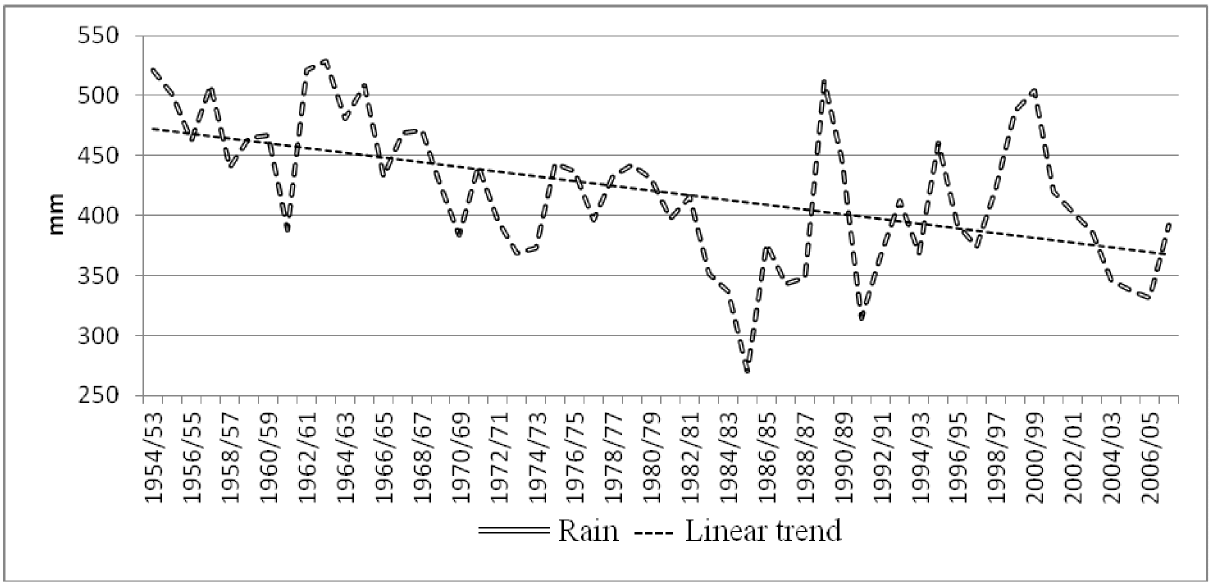
Source: authors' elaboration based on data provided by General Directorate of Agricultural Planning and Economics of the Ministry of Agriculture and Forests

Data make reference to the time period from 1954/53-2007/06. Information on yields has been provided by the General Directorate of Agricultural Planning and Economics of the Ministry of Agriculture and Forests.

Precipitation data till 1999 are those elaborated at the aggregate level for Sudan by Tim Mirchell and available at the web site http://www.cru.uea.ac.uk/cru/data/hrg/. Information from 2000 to 2007 has been provided by the Arab Organization for Agricultural Development disaggregated by meteorological station. This latter has been aggregated at the country level adopting the same methodology followed by Mirchell, that is the simple average precipitation by meteorological station.

Figure 4 shows the historical data for rainfall and its linear trend suggesting a decreasing tendency over the time period taken into consideration and wider fluctuations starting from the 1980s.

Figure 4 – Rainfall: historical data and trend – mm (1954/53-2007/06)



Source: authors' elaborations based on Mirchell and Arab Organization for Agricultural Development

In order to characterise the stochastic model, the likely values assumed by rainfall and its square value are represented by a probability density function (PDF). For rainfall, it makes reference to the historical data of precipitation and it is defined by introducing hypothesis on the lower and upper bound. Harris and Robinson (2001) introduce a normal PDF for precipitation, with values included between $\pm\infty$. On the contrary, this analysis assumes the lower bound equal to zero, due to the fact that precipitation cannot have a negative value, and the upper bound limited but unknown, in order to include extreme weather events, such as floods. Furthermore, the distribution function is not selected a priori as in the above-mentioned study by Harris and Robinson (2001). In fact, it is chosen according to three statistics tests, which measure the compatibility of rainfall and its square value with the selected PDF: they are the Chi-squared statistic (C-S), the Kolmogorov-Simirnov statistic (K-S), Anderson-Darling statistic (A-D) (Palisade Corporation, 2010).

The chosen PDF is substituted to RF , while its square value replaces RF^2. Hence, the stochastic model is estimated for each crop assuming 5,000 iterations. Finally, the output of each stochastic model is represented in the form of a cumulative ascending density function: it expresses the probability that the yield of crop *c* assumes a value less than or equal to some value q_c, that is $F(Q_c) = Prob(Q_c \leq q_c)$ (Risk Assessment Forum, 1997). With reference to this baseline, three values are taken into consideration. They make reference to the predicted mean, upper and lower delimiter values. Their change with respect to the figure in 2007/06 represents the average, the best and worst scenario respectively, simulated with the CGE model. The upper and the lower delimiter values make reference to a 90 per cent probability for the random variable to take on a value included between them.

2.2 CGE model

The paper refers to the CGE model developed at IFPRI by Lofgren et al. (2002) that is adjusted to the specific focus of the analysis and the Sudanese economic features. This is a multi-sectorial, economy-wide model, made up of linear and nonlinear equations describing the payments from each account to the others in a SAM. In particular, the model is calibrated using the 2004 SAM for Sudan (Siddig, 2011). This latter is aggregated for the purpose of the study in a six-sectors-SAM that features 27 accounts (Table 1).

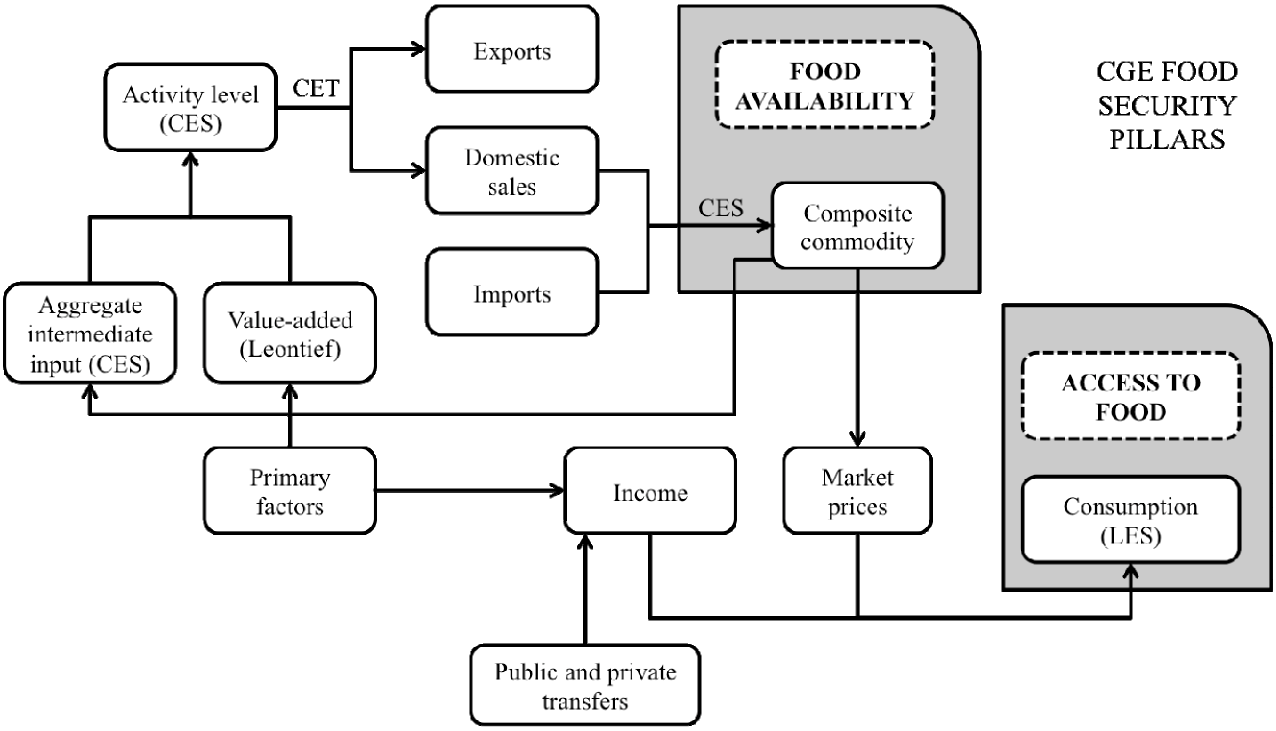
Table 1 – Accounts in the SAM

Activities		Food Industry commodity	CFIN	**Other domestic institutions**	
Wheat activity	AWHE	Industry commodity	CIND	Enterprises	ENTR
Other cereals activity	ACER	Services commodity	CSER	Government	GOV
Other Agriculture Activity	AOAG	**Factors**		**Taxes and other accounts**	
Food Industry activity	AFIN	Labour	LABO	Direct taxes	YTAX
Industry activity	AIND	Land	LAND	Indirect taxes	ATAX
Services activity	ASER	Capital	CAPI	Import tariffs	TAR
Commodities		**Households**		Activity subsidy	ASUB
Wheat commodity	CWHE	High-income households	HHHI	Saving and investment	S-I
Other cereals commodity	CCER	Middle-income households	HHMI	Rest of the world	ROW
Other Agriculture commodity	COAG	Low-income households	HHLI	**Total**	

In the matrix, cereal accounts are those interested by the simulated shocks. Due to the lack of data, millet and sorghum are taken as aggregate in the account “other cereals”. Among institutions, households have a specific importance in the analysis. In the SAM they are disaggregated into three categories according to their level of income.

The structure of the CGE model, illustrated in Figure 5, fits the SAM and identifies activities’ production process, that is the supply side of the model, and the flow of marketed commodities, which is the demand side instead. The model allows analysing two of the basic pillars of the food security concept provided by the 1996 World Food Summit, i.e. food availability and access to food (Sassi, 2006). The former is determined by the disposable amount of composite commodities that, in combination with market prices and household income, brings about the economic access to food, which is represented by consumption. These two dimensions are referred to at the household level of analysis.

Figure 5 – Structure of the CGE model with food security pillars of food availability and access to food.



Note: CES is Constant Elasticity of Substitution function; CET is Constant Elasticity of Transformation function; LES is Linear Expenditure System
Source: authors' elaboration

Within this framework, the stochastic component represented by rainfall affects the value-added function. For this reason, following Harris and Robinson (2001) and Karaky (2002), the value-added equation provided by the standard CGE model is modified. Originally, this function is shaped as:

$$QVA_a = \alpha_a^{va} \cdot \left(\sum_{f \in F} \delta_{f\,a}^{va} \cdot QF_{f\,a}^{\;-\rho_a^{va}} \right)^{-\frac{1}{\rho_a^{va}}} \tag{2}$$

where QVA_a is the quantity of aggregate value-added; α_a^{va} is the efficiency parameter and $\delta_{f\,a}^{va}$ is the share parameter for factor *f* in activity *a*; ρ_a^a is the CES value-added function exponent (that is a transformation of the elasticity of substitution); $QF_{f\,a}$ is the quantity demanded of factor *f* from activity *a*. The modified version of this equation includes a new parameter, namely rf_a^S. That is:

$$QVA_a = [rf_a^S \cdot \alpha_a^{va}] \cdot \left(\sum_{f \in F} \delta_{f\,a}^{va} \cdot QF_{f\,a}{}^{-\rho_a^{va}} \right)^{-\frac{1}{\rho_a^{va}}} \qquad (3)$$

where rf_a^S is the parameter representing the shock to cereal producers ($a = wheat, other\ cereals$) for the three scenarios ($s = average\ scenario, best\ scenario, worst\ scenario$) in the baseline run. As in Harris and Robinson (2001), the shocks are Hicks-neutral technological shocks, meaning that the proportion of inputs for each output remains the same. In equation 3, rf_a^S is such that $0 < rf_a^S < 1$. As a matter of fact, rf_a^S is defined as:

$$rf_a^S = 1 + rain_a^S \qquad (4)$$

where $rain_a^S$ equals the results of the risk analysis.

2.2.1 Model closure

A final aspect taken into consideration for the definition of the CGE model is its closure. The macroeconomic consistency of the model is achieved imposing a number of constraints. These refer to the savings-investment balance, the government balance and the current account balance. Furthermore, since the way macroeconomic variables adjust in the modelled economy is determined by the choice of the constraints (Thurlow and van Seventer, 2002), these latters have to be set up looking at the way macroeconomic causalities work in the Sudanese economy.

In particular, an investment-driven closure is used, with savings being the flexible variable (Elbushra et al, 2010; Siddig, K. and Babiker, 2011). Such a constraint implies savings to adjust as investment varies. Moreover, in the government balance, government savings is the endogenous variable, whereas all tax rates are exogenous (Hassan and Hallam, 1996; Elbushra et al, 2010;

Siddig, K. et al., 2011). Finally, in the current account balance, foreign savings is the flexible variable, whilst the real exchange rate is fixed.

Such a set of constraints seems to fit the Sudanese context for different reasons.

As the closure is investment-driven, the level of investment depends on entrepreneurs' long-term expectations and the role of assuring that investment is fully financed falls on savings. Therefore, in order to enable private savings to follow investment variations, the base-year savings rates of domestic non-government institutions adjust by the same number of percentage points. Nevertheless, in Sudan, the share of government savings in total domestic savings is equal to 68%, thus meaning that government savings plays the most important role in assuring that investment is fully financed (a similar criterion has been adopted by Lofgren et al. (2001) for setting fixed investment quantities in a CGE model for Malawi). Using data from the base simulation in our model, we have calculated this share as:

$$\frac{GSAV}{\sum_{i \in INSDNG} MPS_i \cdot (1 - \overline{TINS_i}) \cdot YI_i + GSAV} \qquad (5)$$

where $GSAV$ is government savings, MPS_i is the marginal propensity to save of domestic nongovernment institutions ($INSDNG$), $TINS_i$ is the direct tax rate for such institutions and YI_i is their income. Hence, $\sum_{i \in INSDNG} MPS_i \cdot (1 - \overline{TINS_i}) \cdot YI_i$ is private savings and, together with government savings, it combines to bring about total domestic savings. This is derived from equation 6, which identifies the savings-investment balance in the model as:

$$\sum_{i \in INSDNG} MPS_i \cdot (1 - \overline{TINS_i}) \cdot YI_i + GSAV + \overline{EXR} \cdot FSAV = \sum_{c \in C} PQ_c \cdot \overline{QINV_c} + \sum_{c \in C} PQ_c \cdot qdst_c \qquad (6)$$

The left-hand side of this equation identifies total savings, whereas the right-hand side describes total investment. In addition to the already defined variables, EXR is the exchange rate and $FSAV$ is foreign savings (i.e. the current account deficit). On the right-hand side, $QINV_c$ is the quantity of investment demand for commodity *c*, PQ_c is the composite commodity price and $qdst_c$ is the quantity of stock change.

Moreover, as Taylor and von Armin (2006) point out, the idea behind flexible government savings is that governments across the globe use automatic stabilisers and public works programmes to counter negative effects of economic downturns, thus meaning the deficit (and not tax revenue) is endogenous. Finally, concerning the current account balance, Sudan has a managed exchange rate regime (Collier and Joshi, 1989; Hassan and Hallam, 1996; Elbushra et al, 2010; Siddig, K. and Babiker, 2011) thus leaving us no choice but to make foreign savings the clearing variable.

3. Results

3.1 The parametric model

Results achieved by estimating equation 1 for millet and sorghum, through an Ordinary Last Square (OLS) method, are illustrated in the following equations:

$$Q_{millet,t} = \underset{(0.0000)}{\overset{1}{0.9665}} * RF_t - \underset{(0.0083)}{\overset{1}{0.0008}} * RF_t^2 - \underset{(0.0000)}{\overset{1}{3.4435}} * T_t + \mu_t$$

$$R^2 = 0.9484;\ F = 312.3\ (0) \qquad (7)$$

(…) p-value

$$Q_{sorghum,t} = \underset{(0.0000)}{\overset{1}{1.4576}} * RF_t - \underset{(0.0006)}{\overset{1}{0.0014}} * RF_t^2 - \underset{(0.0000)}{\overset{1}{2.4659}} * T_t + \mu_t$$

$$R^2 = 0.9752;\ F = 668.5\ (0) \qquad (8)$$

(…) p-value

For wheat, the trend variable is not statistically significant. In risk analysis, the definition of the parametric model represents an important phase because the output of the stochastic model is sensitive to its structure. The literature suggests to consider only the model input parameters that contribute the most to explain the phenomena investigated, excluding those unimportant (Palisade Corporation 2010; Risk Assessment Forum 1997). For this reason, the stochastic model for wheat refers to the following parametric model:

$$Q_{wheat,t} = \underset{(0.0000)}{\overset{1}{3.7784}} * RF_t - \underset{(0.0000)}{\overset{1}{0.0053}} * RF_t^2 + \mu_t$$

$$R^2 = 0.9176;\ F = 289.6\ (0) \tag{9}$$

(…) p-value

In the three equations, the estimated parameters are statistically significant and show the expected sign.

Wheat productivity is the most sensitive to rainfall, followed by that of sorghum and millet. Millet is the most inherently drought-tolerant of all the major staples representing a key cereal grain crop in the dry-lands. In general, millet fits in the same areas of adaptation as sorghum, except that it is somewhat more drought tolerant (http://www.cgiar.org/impact/global/des_fact2.html).

The sign of the estimated parameters suggests that precipitation affects the productivity of all the three crops but at a decreasing rate. Finally, the trend variable has a statistically significant negative impact on sorghum and millet productivity.

3.2 The stochastic model

The stochastic model derives from the above equations, substituting a probability density function to the explanatory variables, that is mm of precipitation and its square value. A Riskbetageneral function fits the historical data of precipitation: all the statistics tests have the lowest value for this distribution function (Table 2).

Table 2 – Rainfall (RF): Specification of the probability distribution functions and statistics test

Function	C-S	K-S	A-D
RiskBetaGeneral(15.401;7,4421;0;622.57)	3.6667	0.3399	0.0807
RiskTriang(0;528.3;528.3)	28.6667	27.2467	0.3561
RiskUniform(0;538.27)	76.6667	+infinity	0.5784

Note: (…) are the arguments of the function

The parametric models are rewritten, substituting to RF the function RiskBetaGeneral(15.401;7,4421;0;622.57), to RF^2 its square value, and to T the number 55 that is the number of observations plus one.

The output from the stochastic model for each crop is represented in terms of a probability distribution function with the indication of the mean value and the delimiters corresponding to a 90 per cent probability. This information is summarised in Table 3.

Table 3 – Output from the stochastic models

	Sorghum	Wheat	Millet
Mean value	224.47	633.36	72.53
Upper delimiter	243.50	673.10	95.40
Lower delimiter	184.60	538.60	33.40

The scenarios simulated in the CGE model are delineated on the basis of these values, calculating the change between each of them and the 2007/06 corresponding figure. Accordingly, the analysis makes reference to the average scenario defined with the mean value, the best scenario with the upper delimiter value and the worst scenario with the lower delimiter value. As previously underlined, the SAM on which the CGE model is based, considers millet and sorghum together in the account "other cereals". Thus, the percentage change for the quantity produced by this aggregate category is obtained as the weighted average of the sorghum and millet values, using the average harvested area of the last ten years as a weight. Table 4 illustrates the shocks (by scenario in the baseline run) that are computed on the basis of equation 4.

Table 4 – Shocks simulated by scenario in the baseline

	Predicted change in rainfall		Shocks	
	Wheat	Other cereals	Wheat	Other cereals
Average scenario	-0.3600	-0.3575	0,6399	0,6424
Best scenario	-0.3198	-0.2667	0,6801	0,7332
Worst scenario	-0.4557	-0.5287	0,5442	0,4712

Looking at the results from the simulations in the CGE model, the best and the worst scenario can be interpreted as the extreme values of an interval within which there is a 90 per cent probability for the impact to happen.

3.3 CGE food security pillars

3.3.1 Food availability

Under the effect of the three scenarios simulated in this paper, food security in Sudan is expected to deteriorate significantly. Indeed, as stressed by SIFSIA (2012), food insecurity is regularly driven by inadequate rainfall.

Figure 6 underlines the negative impact on food availability in terms of quantities of commodities available on the domestic market. The change is stronger for the commodities directly affected by the shocks, i.e. wheat and other cereals. Indeed, for wheat there is a 90 per cent probability for the reduction to be included between -5.32 per cent and -11.71 per cent, while for other cereals the intensity of the shock is expected to be within -16.87 per cent and 34.53 per cent. It is also noteworthy that the lower impact on wheat may be partially due to the lower exposure to rainfall, since the production of this crop is mostly irrigated. Furthermore, since livestock is almost 60% of other agriculture commodity, the majority of the impact on this commodity is related to the indirect impact on livestock. On the other hand, the direct impact of rainfall on livestock has not been taken into consideration because it has been decided to focus on crops.

In this context, the quantities imported (Figure 7 – Panel b) do not counterbalance the reduction in domestic supply (Figure 7 – Panel a). Declining rainfall patterns, indeed, lead to a generalized decrease in area planted and lower yields throughout the country, thereby resulting in lower than average crop production (Goodbody et al., 2012).

Figure 6 – Change in quantity of composite commodities by commodity and scenario

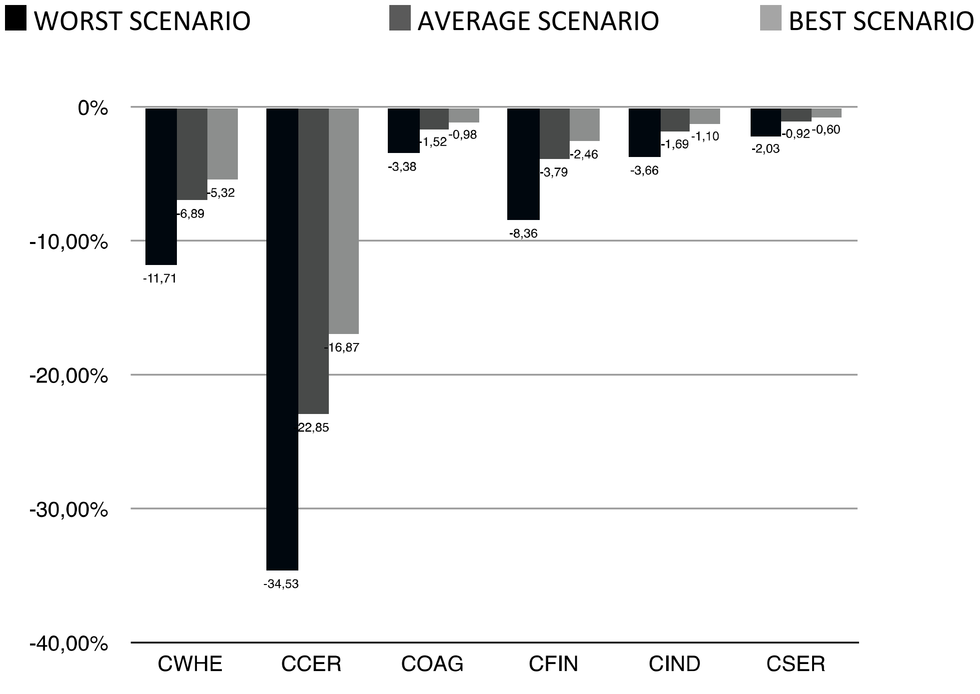
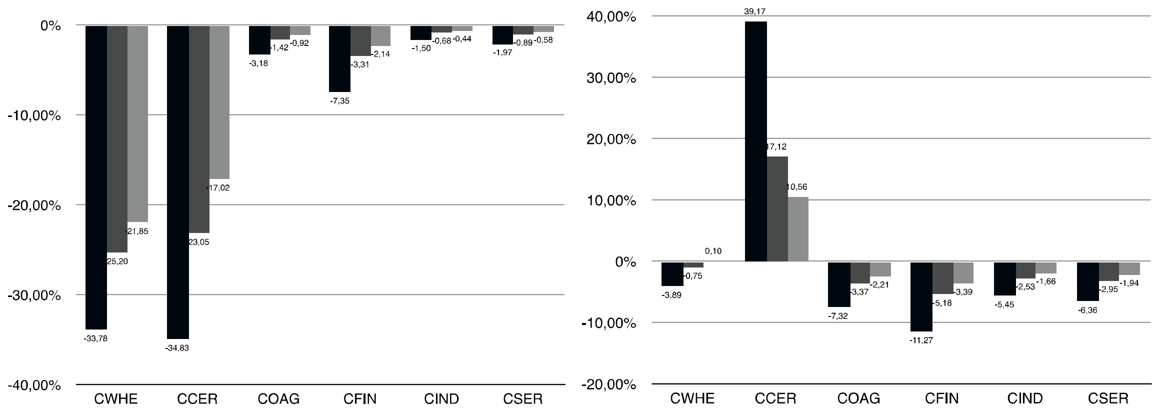


Figure 7 – Change in quantity of domestic supply and of imported commodities by commodity and scenario

■ WORST SCENARIO ■ AVERAGE SCENARIO ■ BEST SCENARIO

a. Change in quantity of domestic supply b. Change in quantity of imported commodities



As far as imported quantities are concerned, it should be noticed that they increase only for sorghum and millet, due to the significant demand price hike for domestic production (Figure 8) that, combined with the elasticity of substitution with domestic demand, generates an incentive to buy on the international market.[1] Such price surge, illustrated in Figure 8, shows a greater variability among the three scenarios within other cereals. Moreover, also the domestic price of wheat increases as a consequence of the shocks, but in this case the intensity of the change, which has a 90 per cent probability to be included between 36.26 and 59.31 per cent, is not marked enough to incentivise a shift from domestic supply towards imports.

Figure 8 – Change in domestic demand price by commodity and scenario

■ WORST SCENARIO ■ AVERAGE SCENARIO ■ BEST SCENARIO

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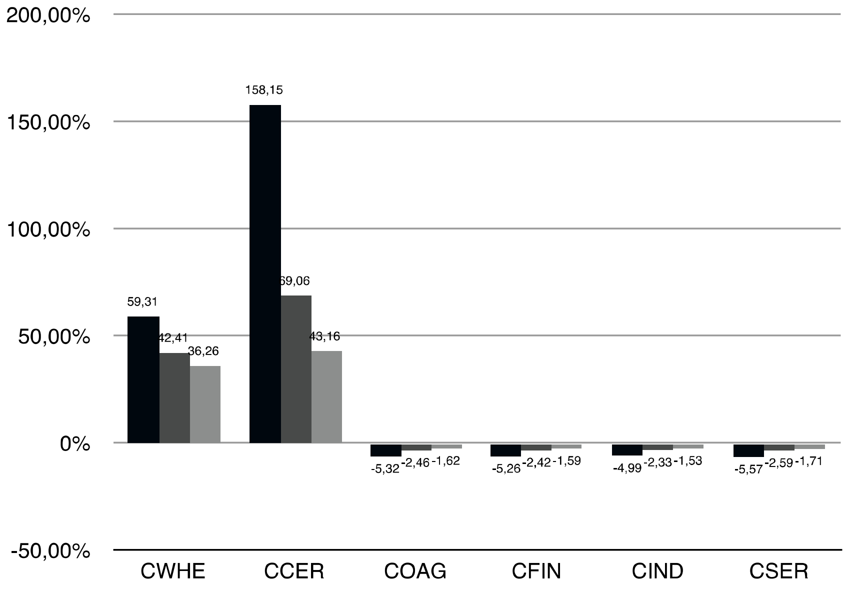
[1] This is formally explained by the equation of the import-domestic demand ratio, which is specified in the model as:

$$\frac{QM_c}{QD_c} = \left(\frac{PDD_c}{PM_c} \cdot \frac{\delta_c^q}{1-\delta_c^q} \right)^{\frac{1}{1+\rho_c^q}} \quad \text{(i)}$$

where QM_c is the quantity of imports of commodity *c*, QD_c is the quantity sold domestically of domestic output, PDD_c is the demand price for commodity produced and sold domestically, PM_c is the import price (in domestic currency). In addition, δ_c^q is the Armington function share parameter, whereas ρ_c^q is the Armington function exponent.
Given the fixed import price in our simulations, a rise in PDD_c causes imported quantities to grow. The responsiveness of such a change, following a modification of $\frac{PDD_c}{PM_c}$, depends on the elasticity of substitution between imports and domestic supply.



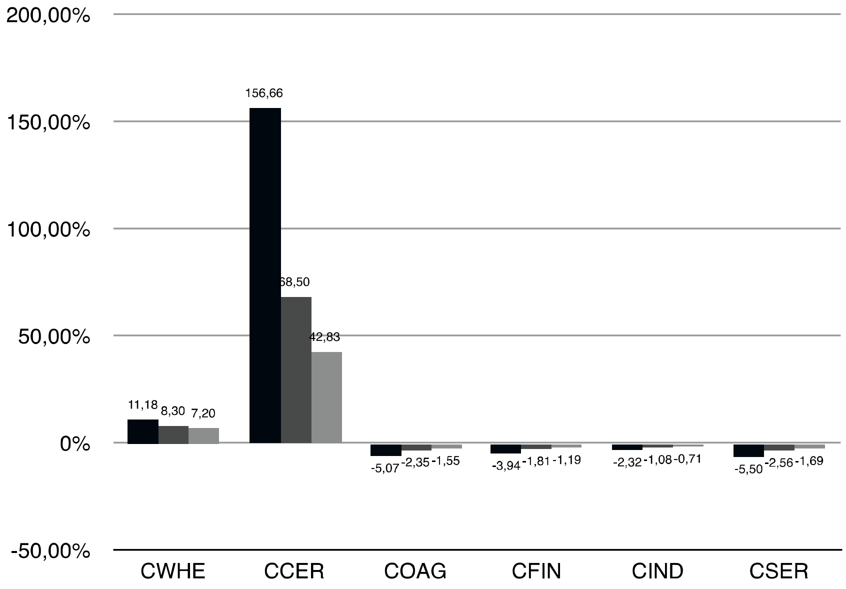
3.3.2 Access to food

Rainfall changes influence crop yields, having an impact not only on local food production and food availability, but also on prices, thus contributing to food insecurity and shortages (Rademacher-Schulz et al., 2012).

On the domestic market the reduction in food availability combines with an increase in prices of wheat and other cereals (Figure 9). Particularly this latter is dramatically affected by the shocks with an expected change included between 156.66 per cent and 42.83 per cent. In this context, consumers are the most negatively affected group, with their food security jeopardized and their living standards reduced (IFAD, 2009).

Figure 9 – Change in price of composite commodities by commodity and scenario

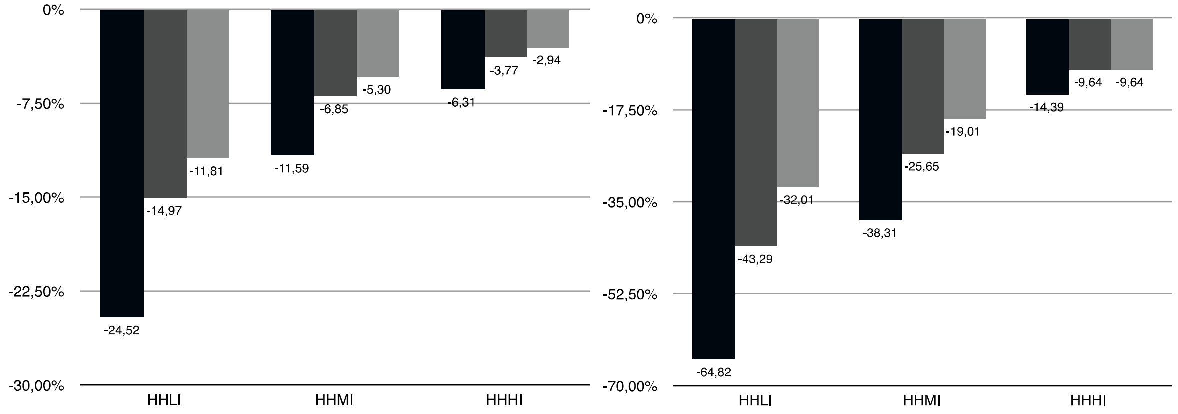
■ WORST SCENARIO ■ AVERAGE SCENARIO ■ BEST SCENARIO



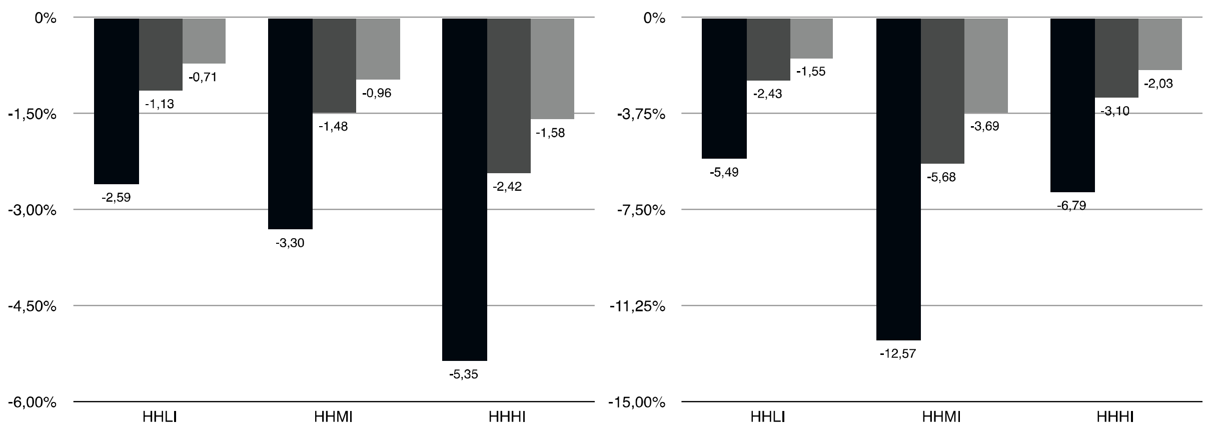
This situation, in a context of 90 per cent probability of a drop in household income that for all the categories is on average between 2 and 6 per cent, explains the result of the simulations on access to food illustrated in Figure 10: all household categories report a reduction in quantities consumed for all commodities.

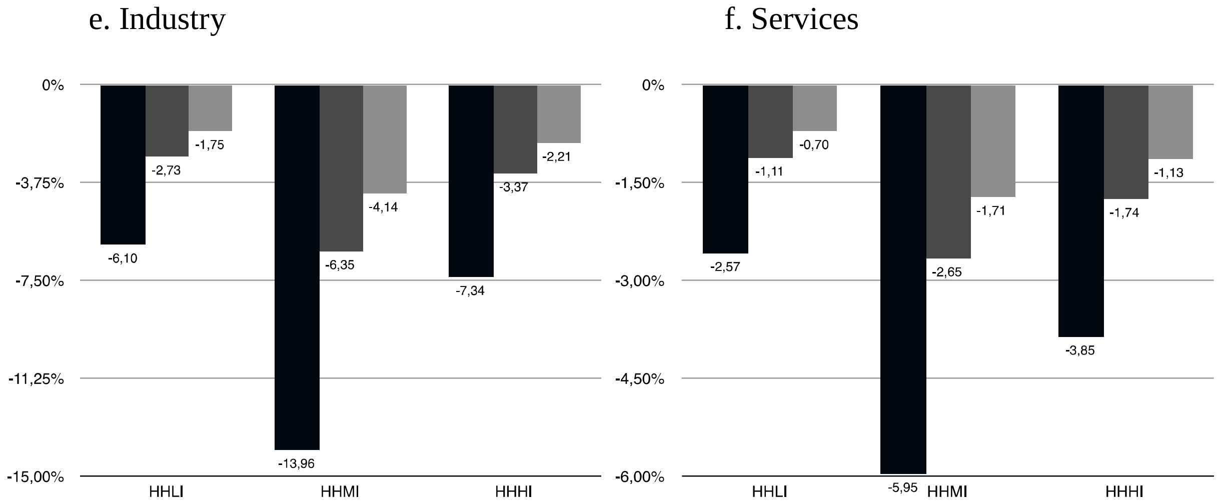
Figure 10 – Change in quantity of consumed commodities by households and scenario

■ WORST SCENARIO ■ AVERAGE SCENARIO ■ BEST SCENARIO


a. Wheat b. Sorghum and millet

c. Other agriculture d. Food industry




e. Industry

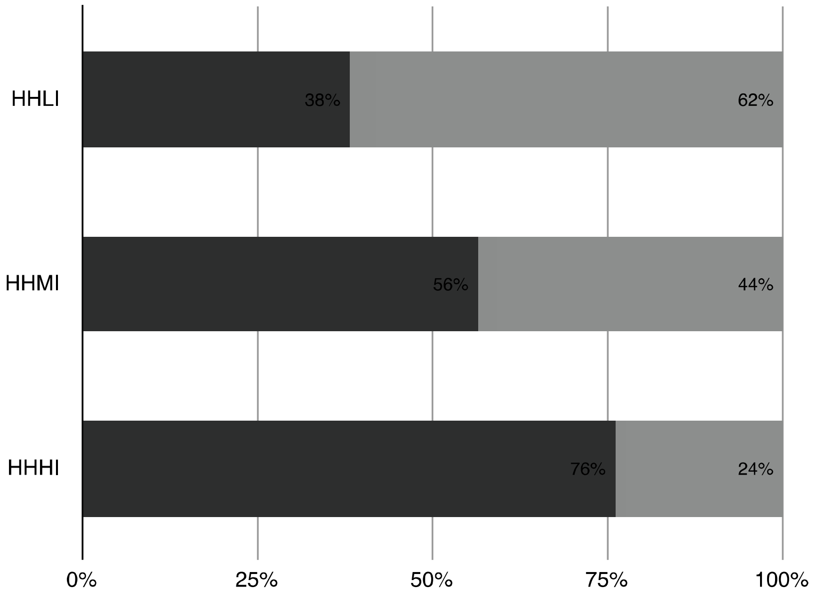
f. Services

Other cereals demand shows the highest expected reduction with the possibility for the low-income households to reduce their consumption by half. In general terms, this household category is the most affected by the shocks simulated on the side of wheat and other cereal demand, followed by middle and high-income households.

However, the direction of the shocks intensity is opposite for other agricultural products: most of the burden of the consequences of the three shocks is on high-income households. Instead, concerning demand for other crops, the greatest fall in quantity consumed is for middle-income households.

A noteworthy issue regards wheat and other cereals. As a matter of fact, the impact on food security of low-income households is even more severe considering that these two commodities are staple food and that, for this household category, other cereals represents more than 50 per cent of their total demand for cereals (Figure 11).

Figure 11 – Share of cereals consumption by household



3.4 Food consumption and aggregate national accounts

The analysis of the production accounts has underlined a typical feature of the Sudanese economy: due to the low level of development of the country, backward and forward linkages are weak. This highlights that the simulated shocks primarily affect wheat and other cereals accounts in a very significant way. However, the scenarios simulated in this paper have an impact also on the macroeconomic accounts, as illustrated in Table 5.

Table 5 – GDP and the aggregate national accounts in nominal and real terms.

NOMINAL	**WORST SCENARIO**	**AVERAGE SCENARIO**	**BEST SCENARIO**
Private consumption	-8.13	-3.74	-2.44
Investment	-4.51	-2.09	-1.38
Government consumption	-5.49	-2.56	-1.68
Exports	6.41	2.88	1.88
Imports	-5.82	-2.59	-1.64
GDP (at market prices)	-4.97	-2.32	-1.53
REAL	**WORST SCENARIO**	**AVERAGE SCENARIO**	**BEST SCENARIO**
Private consumption	-6.47	-3.23	-2.20
Investment*	-	-	-

Government consumption*	-	-	-
Exports	6.41	2.88	1.88
Imports	-5.82	-2.59	-1.64
GDP (at market prices)	-2.28	-1.26	-0.89

*Real investment, as well as real government consumption, does not vary by closure assumption.

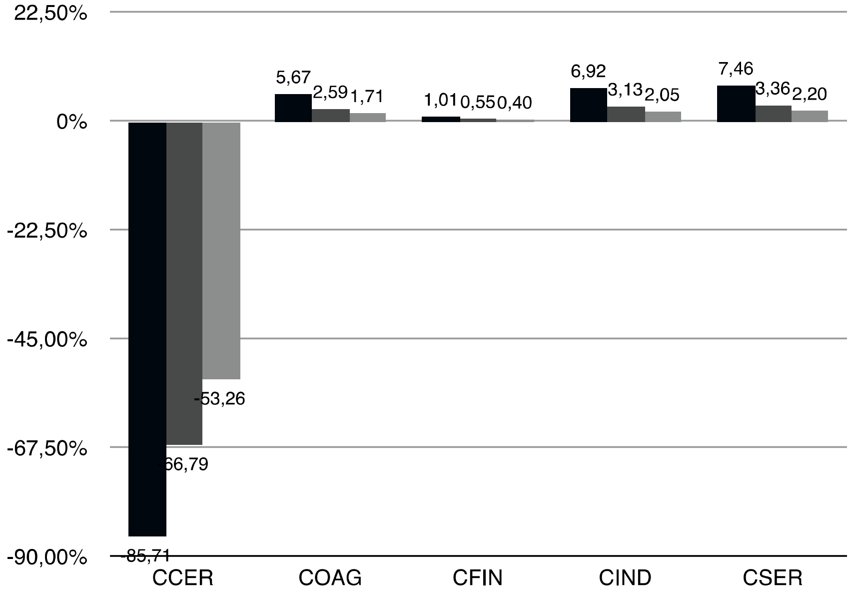
A noteworthy aspect is the inflationary pressure in all the three scenarios. This is the particular result of a “cereal inflation”, as illustrated in Figure 9.

As Webersik (2008) highlights, ups and downs in the country’s economic growth pattern are highly dependent on rainfall. Hence, results show a change in the GDP, suggesting a negative impact on the economic performance of the country that has a 90 per cent probability of being included, in real terms, between -0.89 per cent and -2.28 per cent. This reduction is the result of a contraction in private consumption, while the balance of trade improves.

In nominal terms, the inflationary pressure aggravates the contraction in private consumption, while the emerged reduction in government consumption and fixed capital formation is related to the reduction in prices.

Regarding the balance of trade, two aspects should be pointed out. First, as suggested by Figure 2.b and 12, its improvement is related to the different directions of the shocks on the accounts that are not directly affected by them.

Figure 12 – Change in quantity of exports* by commodity and scenario



*Wheat is not included because it is not exported

The "export incentive" provided to non-cereal activities is related to the reduction in domestic demand prices for these accounts (Figure 8) in a context of fixed export prices, in combination with the elasticity of substitution with domestic demand.[2]

Secondly, the improvement in the balance of trade is also explained by the fact that cereals represent only 0.10 per cent of total exports and 9.34 per cent of total imports.

In addition, concerning the impact on exports, it should be taken into consideration that the results might overestimate the possible change. In fact, about 90 per cent of total exports of Sudan are represented by oil, whereas agriculture represents less than 5 per cent. Particularly, cereals represent about 0.3% of total food and live animal export. Moreover, oil sector is characterised by exports that rely largely on the international market. What is more, it cannot easily adjust to economic shocks through the reallocation of production factor.

Another important negative aspect that has to be highlighted is the reduction in nominal government consumption that represents an important component of the GDP and, thus, of the Sudanese economic growth and development.

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[2] This is captured by the export-domestic demand ration, which in the model is written as:

$$\frac{QE_c}{QD_c} = \left(\frac{PE_c}{PDS_c} \cdot \frac{1-\delta_c^t}{\delta_c^t}\right)^{\frac{1}{\rho_c^t - 1}}$$

(ii)

where QE_c is the quantity of exports, QD_c is the quantity sold domestically of domestic output, δ_c^t is the CET function share parameter and ρ_c^t is the CET function exponent.

4. Conclusions

By integrating a stochastic and a CGE model, this paper has investigated the consequences of different rainfall scenarios on food security in Sudan with a specific focus on food availability and household access to food.

From 1953/54 to 2006/07, precipitation in Sudan has reduced and the estimated parametric model has confirmed its direct correlation with the productivity of sorghum, millet and wheat and the decreasing rate of its intensity over time as suggested for the 1980s by Teklu et al. (1991). If the historical rainfall trend is confirmed, the stochastic model has predicted a further reduction of the yield for the three selected crops, confirming the expectations provided by the literature (UNEP, 2007; NAPA, 2007). On the basis of these predictions, the CGE model has suggested a dramatic deterioration of both food availability and access to food as a consequence of the likely predicted rainfall pattern; this is in line with the achievement of the World Food Programme (2012) according to which below-average rainfall and delayed rains have a serious impact on food security.

In the model, the decline in food availability is due to a marked reduction in the quantity of cereal commodities available on the domestic market. This is consistent with the literature arguing that the most direct impact of climate change on food security is through availability due to changes in crop productivity (Thompson et al., 2010). In the Sudanese case this situation is aggravated by a reduction in cereals import incentives.

The worsening in access to food, instead, arises from the combination of the expected drop in household income and the major cereal inflationary pressure. As a consequence, all household categories are affected by the rainfall shocks simulated, with the biggest impact on the poorest households. This was an expected result taking into consideration that the poorest spend more than 80 per cent of their total budget on food and that half of their total demand is for cereals (SIFSIA, 2012).

The CGE model has also made possible to identify the main macroeconomic causalities in the Sudanese economy, following the impact of rainfall shocks on food security. In this respect, the paper has first allowed addressing the open question about the possible effects of climate change and improved variability on economic growth rates (Tol, 2010). The predicted contraction in private consumption under the simulated scenarios is the main responsible for the expected negative economic performance of the country. This paper has suggested a 90 per cent probability for the GDP to drop between 0.89 and 2.28 per cent; the result is in line with the study by Dell et al. (2008)

who argue that climate change causes a contraction of the economy of poor countries between 0.6 and 2.9 per cent.

In this context a question arises: are policies for climate change and improved variability alone able to reduce the impact of less rainfall on food security in Sudan?

The literature is focused on different levels of analysis. A part of it emphasises the role of climate change policies, while another deems development interventions as viable alternatives to them, underlining the fact that they may have negative and perverse effects on economic development (Tol, 2010). Other authors study alternative solutions to climate policies, taking into account the possibility to act on non-climatic factors (Shcelling, 2000) or to introduce adaptation and coping strategies (Huq and Ayers, 2009).

This paper does not advocate a specific policy intervention being better than others, nor it acknowledges that one area needs to be prioritised. Instead, this work clearly stresses the need to evaluate a different possible policy perspective: climate change, poverty and food insecurity are strongly interlinked, thereby suggesting a coordination of policies in these three targeted areas of intervention. In the policy-making process, it should be opened a dialogue among these three areas, with a sound integration of climate change policies with those aimed at promoting development and food security.

Results achieved also suggest at least three further directions of the analysis.

The paper has followed the literature that uses stochastic CGE models or CGE models with risk components but an improvement would be towards the adoption of a dynamic CGE model that explicitly incorporates uncertainty about the future.

Another eventual enhancement might consist in using a regional CGE model in order to take into consideration the high geographical variability in rainfall distribution across the country. In this respect, the regions should correspond to the climatic zones. As a matter of fact, Sudan is characterised by multi-climatic areas. In the north the climate is arid, while the south is influenced by a tropical wet-and-dry climate. The central and the northern part have also experienced repeated and prolonged droughts in the last decades, even if severe flooding is also common in the country. However, data needs represent a major constraint.

Finally, an analysis developed at the regional level also has the advantage to refine the model in order take into account also the evapotranspiration and, in other words, the effective rainfall by crop.

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