AGRICULTRAL PRODUCTION AND TRADE UNDER CLIMATE CHANGE IN SUDAN

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The aim of this paper is to evaluate the impact of climate change on agricultural production and agricultural trade s in Sudan. Agriculture is the main sector of Sudan's economy. Sudan is among one of the least developed countries (LDCs). The country is characterized by its small-open economy, and the economic performance is depend on weather conditions especially rainfall. Between the mid-1970s and late 2000s, summer rainfall decreased by 15–20 percent across parts of western and southern Sudan. These declines can be visualized as a contraction of the region receiving adequate rainfall for viable agricultural livelihoods. This study has developed a multi-market model for Sudan, the model embodied important characteristics of agriculture in Sudan including the substitution effects and the dependency of agricultural supply on rainfall. The major markets of the Sudanese agriculture products are simulated by calibrating their supply and demand functions. The model has introduced stochastic variables which are supply, prices and rainfall; it has also incorporated agricultural trade indicators, which are directly affected by the agriculture performance. The model scenario simulations revealed that, the impact of the decreasing trend of rainfall would overall lead to considerable losses in Sudan's agricultural supply and hence a deterioration in the country's external sector.

Keywords: Sudan, agricultural trade, Climate change, Multimarket model

1. Introduction

Sudan is a country endowed with huge natural and human resources. Although it is rich in natural resources, the country is classified as least developed, low-income and food-deficit country. The country is ranked 169th according to the UNDP Human Development Report in 2011. Sudan, like many African countries is ruled by rainfall more than politics (Ali and Elbadawi, 2002). Between the mid-1970s and late 2000s, summer rainfall decreased by 15–20 percent across parts of western and southern Sudan. These declines can be visualized as a contraction of the region receiving adequate rainfall for viable agricultural livelihoods.

The share of agriculture in Sudan's non oil foreign trade is almost 80% of exports. This is mainly in the form of raw materials with the main agricultural commodities exported being cotton, gum Arabic, sesame, livestock and groundnut. Sorghum is the most important annual crop, it is mainly produced in the rain fed sector, contributing about 80% of the total production while the share of the irrigated sector is around 20%. Sudan also produces about 80% of the total world production of Gum Arabic which grows naturally in the rain fed traditional sector and is considered one of the most important export crops. Millet is another important crop that is mainly produced in the traditional rain fed sector with special importance in western Sudan. Wheat is primarily grown under irrigation in the Gezira scheme, New Halfa, Rahad, Northern states, and White Nile State. Groundnut is produced both in the irrigated and traditional rain fed sectors. Sesame is produced totally in the rain fed sector and mainly for export, nationally, it is utilized for production of edible oil and the manufacturing of sweets.

Agriculture historically generated the bulk of Sudan's foreign exchange earnings through a diversified basket of exports which can be broadly classified into three categories that include field crops, animal and forest exports. The main field crops exports include cotton, sesame and ground nut, while animal exports include sheep, camels and cattle, and, gum arabic represents the major forest exports. The share of agricultural exports in total country's exports is declining because of the growing exports of oil sector; this share has declined to only 4.4% in 2008 compared to14.6% in 2001. Sudan enjoys the preconditions for a strategy of boosting its agricultural exports, which started to decline in terms of value each year since its peak in 2004 of $569 million to an estimated $508.9 million in 2008 table (1). The major import food in Sudan is wheat. Due to low and variable domestic production, imports of wheat and wheat flour in terms of wheat equivalent have been escalating, reaching about 1.183 million tons in 2008 compared to about 0.52 million tons in 2001. The value of imported wheat has increased from US$ 109.6 million in 2001to US$ 715.3 million in 2008 (table 1). Total cereal production in the country has ranged over the last five years between 4 and 6 million tones. It accounts for about 65% to total annual grain requirements (El-Dukheri 2007).

Table (1) Agricultural Exports And Wheat Imports In Sudan 2001-2008

Year	Agriculture Exports (Million US$)	Share of Agriculture Exports in Total Exports (%)	Wheat Imports Quantity (million tons)	Wheat Imports Value (Million US$)
2001	240.6	14.9	0.52	109.7
2002	356.2	18.8	1.03	199.3
2003	410.3	16.1	0.90	190.5
2004	590.7	16.5	1.06	255.6
2005	578.8	12.0	1.45	373.9
2006	569.4	10.0	1.36	336.5
2007	412.3	4.6	1.13	363.6
2008	508.9	4.4	1.18	715.3

Source: Bank of Sudan, Annual reports (2001-2009)

Sudan agriculture and agricultural trade is depending mainly on rainfall, the incidence of climatic changes represents by low trend of rainfall which is expected to negatively affected agricultural production and trade of the country. The main objective of the study is to: Assess the responses of economic variables (Supply and demand) of agricultural commodities to climate change and their consequences on agricultural trade of the country.

A multi market model is used as a main tool to analyze the impact of climate change on the agricultural trade of Sudan. The model under consideration takes the normal specification of a standard partial equilibrium model; it is static and consists of a set of demand and supply equations for each commodity with the level of production and demand determined by factors including prices, income, demand and supply-shift variables and various other assumptions about policies. Some variables in the model are expressed in their stochastic form; these are the prices, quantities and rainfall.

The paper is organized as follows. In the next Section literature review is discussed. In section 3 the multi-market model is laid out with the main two scenarios used in the model. Section 4 represents the model results for agricultural supply and trade under the two scenarios. In section 5 conclusions are presented.

2. Literature review

Considerable attention has been given to climate change and its impacts. Agriculture is considered to be one of the sectors most vulnerable to climate change, and also represents a key sector for international trade. In low-latitude regions, where most developing countries are located, reductions of about 5 to 10 per cent in the yields of major cereal crops are projected (UNEP and WTO, 2009).

Livelihood in Eastern and Southern Africa is strongly dependent on rainfall distribution and land management practices among smallholder farmers. Over 95 % of the food producing sector is based on rain fed agriculture (Rockström et al, 2004). The exposure to a high degree of climate risk is a characteristic feature of rain fed agriculture in the dry lands of sub-Saharan Africa and parts of South Asia. Climate change is expected to intensify many of the challenges facing dry land agriculture in Africa and South Asia, but in ways that can only be partially anticipated (Brown and Hansen, 2008)

Many developing countries in Africa are seen as being highly vulnerable to climate variability and change (Slingo et al., 2005), in part because they have only a limited capacity to adapt to changing circumstances (Thomas and Twyman, 2005). A climate sensitivity analysis of agriculture concluded that some African countries will virtually lose their entire rain-fed agriculture by 2100 (Mendelsohn et al., 2000).

Studying climate change impact on trade is an issue addressed by many scientific researches. In a study under a project for the Renewable Natural Resources and Agriculture UK 2007, considering climate change scenarios revealed that agricultural land suitable for cereal crop cultivation will have significant losses predicted in northern and southern Africa, due to a worsening of growing conditions from increased heat and water stress. simulations also predict a growing dependence of developing countries on net cereal imports, totaling in 2080 between 170 million ton and 430 million ton. The comparative advantage for producing cereals is predicted and net imports of developing countries increase by about 25%, i.e. between 90 and 110 million tons of additional cereal imports. (Fischer et al., 2005).

Blignauta et al, 2009 employed a panel data econometric model to estimate how sensitive the South African's agriculture may be to changes in rainfall. Net agricultural income in the provinces, contributing 10% or more to total production of both field crops and horticulture, is likely to be negatively affected by a decline in rainfall, especially rain-fed agriculture. For the country as a whole, each 1% decline in rainfall is likely to lead to a 1.1% decline in the production of maize (a summer grain) and a 0.5% decline in winter wheat. These results are discussed with respect to both established and emerging farmers, and the type of agriculture that should be favored or phased out in different parts of the country, in view of current and projected trends in climate, increasing water use, and declining water availability.

3. Methodology

3.1 A Multi-market Model for Sudan General Features

In the multi-market model the interaction between supply and demand functions explains the behavior of producers and consumers in the market. The model starts by formulating supply and demand functions where prices and rainfall are assumed to play a major role in the model; it works as entities of the determination of supply and demand equations for all commodities. Domestic prices are assumed to be linked to world market prices which in turn are determined by the world demand and supply.

In this study the supply equation is calibrated as a function of prices and non-prices variables, the non-price variable is represented by rainfalls, many studies had included non-pricing variables in estimating supply so as to have unbiased and plausible results (Abrar et al, 2002, Lamb, 1999, and Larsson, 1996)

The model assumes the homogeneity of the products and the perfect competition on the market. The final result depends on the elasticities in the model which are taken as exogenous and constant. The supply and demand equations are represented by isoelastic (Cobb-Douglas) functions in which the price and income elasticities are constant (Kirschke and Jechlitschka, 2002). Isoelastic functions were chosen due to the convenience of their interpretation. In addition, they were widely used to study the implementations of agricultural policy and trade (Kirschke and Jechlitschka, 2002, Jechlitschka and Lotze 1997).

3.1.1 The Supply Equations

There are ten major commodities considered in the model. The supply of each is assumed to be uncertain and represented by the quantity produced which is function of its own price and the prices of the competing commodities in addition to rainfall. Quantities, prices and rainfall are considered as uncertain variables. The product supply equations represented as follows:

$$q_i^s = c_i * (p_i^s)^{\varepsilon_{ii}} * \prod_{j \neq i} (p_j^s)^{\varepsilon_{ij}} * (R^r) \ , \qquad i, j = 1, \ldots, 10$$

Where

q_i^s is the amount of the i th commodity supplied

c_i is the supply calibration coefficient of the i th commodity

p_i^s is the supply price of the i th commodity

p_j^s is the supply price of the j th product

R^r is amount of rainfall

ε_i is the supply price elasticity of the i th product

ε_{ij} is the supply cross price elasticity of the j th products that are competing the i th product

r rainfall elasticity

j is the set of relevant product that compete with the i th product.

3.1.2 The Demand Equations

On the other hand, the demand (consumption) quantity of a commodity is set to depend on its own price, the prices of close consumption substitutes or complementary commodities and the consumer per capita income. Demand and prices are considered as uncertain variables. So, the system of the demand function can be expressed as follows:

$$q_i^d = b_i * (p_i^c)^{\eta_{ii}} * \prod_{i \neq j} (p_j^c)^{\eta_{ij}} * I^{\mu_i}, \qquad i,j = 1,\dots.10 \qquad \cdots \quad (2)$$

Where

q_i^d is the amount of the i th commodity demanded

b_i is the demand calibration coefficient of the i th commodity

p_i^c is the demand price of the i th commodity

I is per capita income

η_i is the demand price elasticity

η_{ij} is the demand price elasticity of the i th commodities that are complementary or substitutes for the i th commodities.

μ_i is the income elasticity of the i th commodity.

The term *I* represents the per capita income of the consumer which is calculated in the model as the outcome of the Gross Domestic Product over the number of total population. This term could also provide the possibility of exploring future developments that may happen in the demand side (KARIM, 2002).

3.1.3 Trade indicators

3.1.3.1 Total Exports, Total imports and Balance of Trade

Total agricultural exports, imports and balance of trade are calculated in the model as

$$TEx = \sum(q_{i-}^s q_i^d) * p_i^w \quad i = 1,\dots., 9$$

$$TIm = \sum(q_{i-}^d q_i^s) * p_i^w \; i = 1,\dots\dots.9$$

$$BOT = TEx - TIm$$

Where TEx and TIm in the model agricultural export and import values.
BOT is balance of trade
q_i^s and q_i^d supply and demand of the coomodities
p_i^w world market price

All three indicators are presented in their stochastic distributions since prices and supply and demand quantities are stochastic.

3.2 Specific Assumption of the Sudan Multi-market model

The model includes ten major agricultural commodities in Sudan, namely wheat, rice, sorghum, millet, sesame, groundnut, sugar, cotton, gum Arabic and Livestock. The commodities represent the exported, imported and locally traded commodities in the Sudan. Where, sesame, groundnut, sorghum, gum arabic and livestock are the main exports from the rainfed sector, cotton and sugar are the exports of the irrigated sector, while wheat and rice are import substitutes and millet is the local-traded crop. The elasticities in the model are obtained from secondary data sources.

Prices and rainfall are the main variables in the supply and/or demand functions that are represented in their stochastic distribution with the help of the ***BestFit*** software. The model is built in the Excel Spreadsheet which is necessary to run @Risk functions used to express and analyze the uncertainty variables in the model. The major assumptions are that the Sudan has an open market economy, for simplicity, Sudan is considered as a small country in the world market for all export and import commodities.

Time-series data covering the period between 1990 and 2006 were used. Data on agricultural output, farm-gate prices and rainfall were obtained from the Department of Agricultural Economics and Statistics, Federal Ministry of Agriculture and Forests, Sudan. The second major part of the secondary data is the supply, in which the production of all commodities in the basic model is shown in the form of their distribution functions. Third, the prices of all commodities also are presented in their distributional form, in the model the rainfall has normal distribution (Normal (519.607, 94.812)), the distributions are derived from the time series data with a help of the *BestFit* software. Finally, elasticities of supply and demand functions which include own price elasticity, cross elasticties, rainfall elasticity in addition to the income elasticity were obtained from past researches.

3.3 The Scenarios

The model incorporate the following

1. The basic model is calibrated with time series data for all stochastic variables for the period 1990 to 2006 .
2. The impact of climate change represented by 20% decrease in rainfall with distribution Risk Logistic (443.655, 54.604) .

3.3.1 The climate change Scenario

The production of exported agricultural crops especially sesame, ground nuts, gum Arabic and livestock is depending mainly on rainfall. Furthermore, most production and nearly all smallholder cultivation are rain-fed and grown during the summer rainy season between July and December. Agricultural exported crops are therefore highly sensitive to rainfall and, to climatic variability more generally. Apart from the direct and indirect price incentives, there are various non-price factors that affect the agricultural supply response. Among the most prominent factors are investment in infrastructure, agricultural research, and agro-climatic conditions (Mamingi, 1997). In the model, the rainfall has the normal distribution of (Normal (519.607, 94.812)). The climate change sc scenario is simulated by taking the distribution of 20% low rainfall trend with distribution Risk Logistic (443.655, 54.604). The relationship throughout the country between production volatility and climatic events is striking. Different sequences in drought impacts at country level are reflected in year- to-year changes in crops yields and agricultural GDP. Nevertheless, focusing on rainfall and output provides a better understanding of the consequences of climatic variability historically and in the future with implications for trade sector and economic policy. In summary, climate change remains the most likely source of export downfall and climate related economic shock.

3.4 Model Estimation

Risk analysis by using @Risk software is a quantitative method that seeks to determine the outcomes of a decision situation as a probability distribution using Mont Carlo or Latin Hypercube simulations to do the risk analysis. The incorporation of the risk in the multi-market model and the analysis of the model under uncertainty are carried out by using @Risk software. The uncertain (Stochastic) variables in the model are presented in their probability distribution functions by the help of ***BestFit***; a software within the @Risk program. The final results could be graphed in the form of cumulative distribution function (*CDF).*

4. Results and discussion

4.1 The Supply effect of climate change Scenario

In climate change scenario the average level of rainfall with 20% drop in rainfall was applied to the model. Table (2) indicate the expected possible changes in the supplies of the commodity markets of the major Sudanese agriculture commodities resulting from rainfall occurrence. Of course the low trend of rainfall has generally negative impact on the whole agricultural sector.

The information in table (2) shows that cereal food crops demonstrate a considerable decrease in their supplies, especially of sorghum and millet in comparison to food import crops of wheat and rice. That is because sorghum and millet are mostly produced in the rain-fed sector. The simulation results showed that the drop in sorghum supplies could reach 16.43% that is from 3,418,672 ton at probability of 0.56 to 2,852,631 ton at lower probability level of 0.52. Millet supplies might decline by 16.4% that is from 428,081 ton to 357,737 ton at probability level of 0.35.

Wheat supply declines by 7.2% with probability of 0.6; this is in comparison with 39694.16 ton at lower level of probability of 0.56 in the basic scenario. While the decrease in rice supply is at 8.3%, that is; from 3,441 ton at 0.7 probability level.

Oil seeds export crops of sesame and ground nut show anticipated decrease. Sesame supply could falls by 16.8% that is from 217,952 ton at probability of 0.56 to 181,242 ton at probability 0.52. While GN decreases by 17% from 621,160 in the base model to 514,866 ton in the climate change scenario at the same level of probability.

The supplies of irrigated sector export crops of sugar and cotton show a fall of 7 percent and 8.9 percent respectively compared to the base model in which the mean supply cotton is 427,506 bales and produced at 0.5 level of probability, while sugar mean supply is 518,465 ton at the probability level of 0.6. gum Arabic as a forest crop would experience a remarkable decline of its supplies. While, Livestock which depends for grazing on the natural pasture, they are affected directly by the shortage of rain and the supply could drop by 18 percent.

Table 2: The impact on supply, the climate change scenario

Commodity	**Moment**	**Supply Basic Scenario**	***P***	**Supply Climate change scenario**	***P***	**% Δ**
Wheat (ton)	Mean	396,942	0.56	368,196	0.6	-7.2
	Std Dev	225,566		209,440		
Rice (ton)	Mean	3,441	0.7	3,157	0.68	-8.3
	Std Dev	4,590		3,984		
Sorghum (ton)	Mean	3,418,672	0.56	2,852,631	0.52	-16.6
	Std Dev	1,751,492		1,410,250		
Millet (ton)	Mean	428,081	0.53	357,738	0.35	-16.4
	Std Dev	249,550		206,967		
Sesame (ton)	Mean	217,953	0.56	181,424	0.52	-16.8
	Std Dev	97,806		77,860		
GN (ton)	Mean	621,367	0.6	514,866	0.61	-17.1
	Std Dev	406,938		330,016		
Sugar (ton)	Mean	518,465	0.61	481,737	0.63	-7.1
	Std Dev	143,062		132,000		
Gum Arabic (ton)	Mean	26,205	0.64	21,412	0.64	-18.3
	Std Dev	20,182		17,287		
Cotton (bale)	Mean	427,507	0.5	389,586	0.51	-8.9
	Std Dev	132,874		119,090		
Livestock (head)	Mean	33,465,340	0.6	27,400,000	0.57	-18.1
	Std Dev	17,756,840		11,900,000		

4.2 The impact of climate change on the trade Sector

Table (3) explain the effect of climate change on the traded agricultural commodities. In general, under the climate change scenario, the import value of wheat, rice, and sorghum would increase while exports of sesame, gum Arabic sugar will decrease. GN and livestock which are normally exports commodities will shift to be imported crops, and, millet as well which is used to be a self-sufficient crop.

Export crops which are grown totally under rain fed areas sesame and gum Arabic will show decrease in their exports value by 8.1% and 4.1% respectively, While GN will shift from exports to be an imported crop at a value of $ US 21,117,171. Livestock also will shift to be imported at a value of $ US 106,600,232. Concerning sugar and cotton which are the export crops mainly grown under irrigated sector will show a remarkable decrease in their export value.

Imports from sorghum would increase considerably by 103.8% under the climate change scenario to a value of $ US 114,239,282. This is because sorghum is the main staple food for rural population. Millet is normally a non-traded crop and the country is self sufficient of it, however, the climate scenario revealed millet might become an import crop with import value of $ US 11,037,935.

Table 3: Agricultural Traded crops export and import value, base and climate change models

	Export Value $ US		Change	Import Value $ US		Change
	Base model scenario	Climate change Scenario		Base model scenario	Climate change Scenario	
Wheat	0	0	0.0	178,088,472	183,929,879	3.3
Rice	0	0	0.0	10,625,349	10,783,139	1.5
Sorghum	0	0	0.0	56,047,677	114,239,282	103.8
Millet	0	0	0.0	0	11,037,935	100.0
Sesame	149,028,936	136,948,739	-8.1	0		0.0
GN	5,639,045	0	-100.0	0	21,117,171	100.0
Sugar	20,111,318	19,063,959	-5.2	0		0.0
GumArabic	37,245,571	35,732,567	-4.1	0		0.0
Cotton	86,622,967	80,659,092	-7.4	0		0.0
LiveStock	197,292,962	0	-100.0	0	106,600,232	100.0

Table (4) and figure (1) shows the impact of the climate change on the external sector in total. The major agricultural exports from the rain fed sector are, sesame, groundnut, sorghum, livestock and gum Arabic. The *CDF* explains that, at the incidence of climate change, total exports could decrease by 127% that the value of exports could decrease on average from $461,857,400 at p of 0.59 to. $ -124,544,700 at *P* of 0.6 , which means that the country will turn to import on its major agricultural markets especially sorghum, millet, ground nut and livestock. On the other hand, total agricultural imports which are mainly the imports of wheat and rice also show an increase in their values as a result of climate change . Total import value might increase by 9.5% that is from $189,199,600 at *P* level of 0.52 to $207,189,400 at 0.51 *P* level. The increase of imports is mainly to substitute loses in local cereal production of sorghum and because of the considerable increase in the value of imports. The result of increase in imports and the decrease of exports is shown by a deficit in agricultural balance of to reach 221.8% in compare to the basic scenario, that is from a positive balance of $272,712,300 to $ - 332,287,600 exploring on one hand the decrease in agricultural markets exports of sesame, ground nut, gum Arabic and livestock, on the other hand the increase of wheat and rice imports.

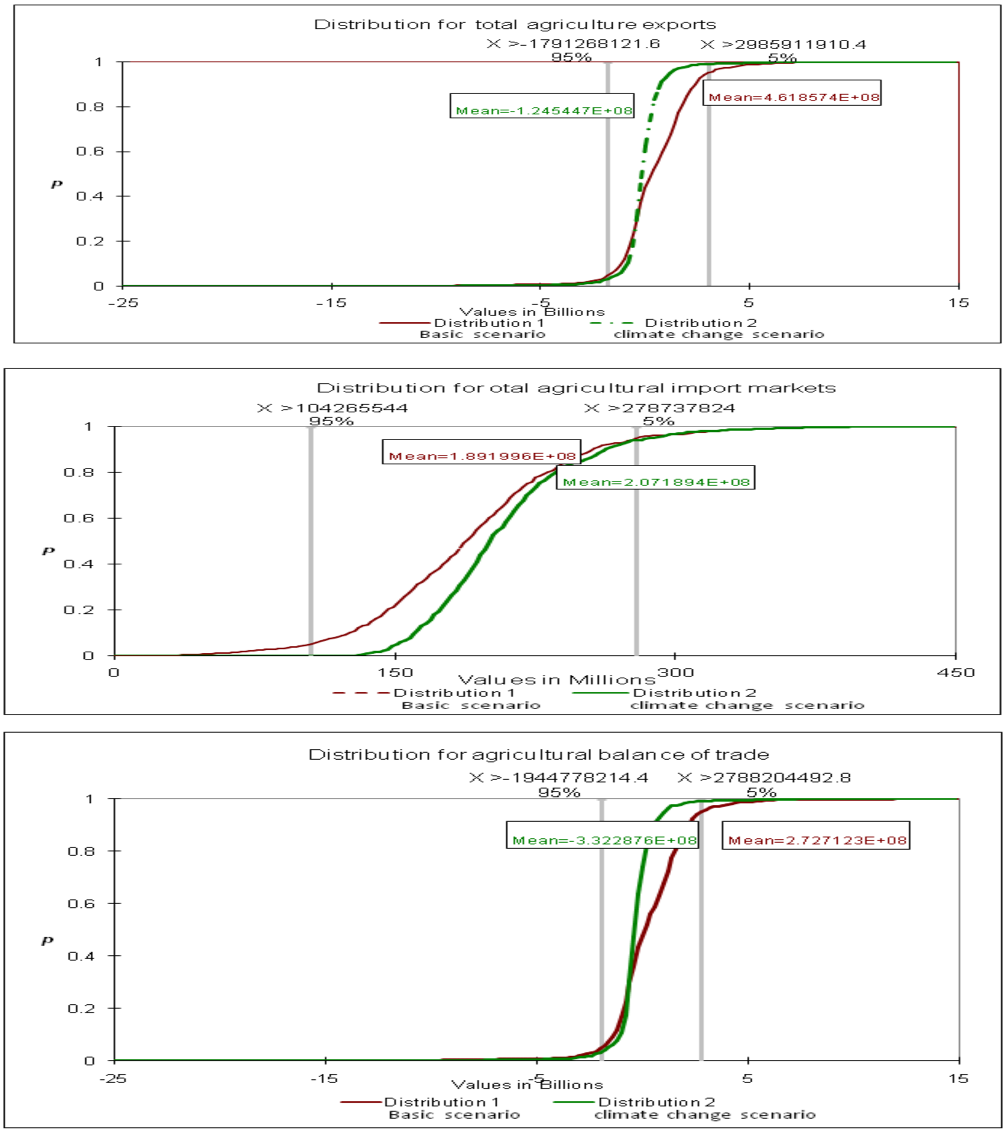

Figure 1: The *CDF* distribution of the trade sector indicators, the effect of climate change

Table 3: The impact of climate change on trade sector

	Base Model			Climate Change Scenario		
Item	**Moment**	**Value $**	***P***	**Value $**	***P***	**% Δ**
Total Exports	Minimum	-$21,988,920,000		-$10,173,290,000		
	Mean	$461,857,400	0.60	-$124,544,700	0.59	-127.0
	Maximum	$13,974,240,000		$9,737,133,000		
	Std Dev	$1,940,118,000		$1,068,847,000		
Total Imports	Minimum	$12,198,550		$119,637,900		
	Mean	$189,199,600	0.52	$207,189,400	0.51	9.5
	Maximum	$442,868,000		$395,292,200		
	Std Dev	$55,765,580		$41,663,220		
BOT	Minimum	-$22,240,950,000		-$10,320,720,000		
	Mean	$272,712,300	0.59	-$332,287,600	0.61	-221.8
	Maximum	$13,863,730,000		$9,518,455,000		
	Std Dev	$1,943,803,000		$1,070,428,000		

5. Conclusion

Sudan agriculture and agricultural trade is depending mainly on rainfall, the incidence of climatic changes represent by rainfall degradation is expected to negatively affect the agricultural production and trade of the Sudan. Using a multi-market model, a shock of climate change scenario represented by low rainfall was applied to stochastic multi-market model.

The climate change scenario has generally negative impact on the whole agricultural sector of Sudan. Cereal food crops show a considerable decrease in their supplies, especially sorghum and millet compared to food import crops of wheat and rice. That is because millet is mostly produced in the rain-fed sector. The decrease in sorghum supplies could reach 16.43%.

In general, under the climate change scenario, the import value of wheat, rice, and sorghum would increase while exports of sesame, gum Arabic sugar will decrease. GN and livestock which are normally exports commodities will shift to be imported crops, and, millet as well which is used to be a self-sufficient crop.

the value of imports of import substitutes show a remarkable increase to compensate the loss of sorghum and millet. exported crops of sesame, ground nut, gum Arabic and livestock show a considerable decrease which reflected in low export value. The result of increase in imports and the decrease of exports is shown by a deficit in agricultural balance of trade in Sudan as a result of climate change.

References:

Abdel Karim E. E., (2002), The Impact of Uruguay Round Agreement on Agriculture on Sudan's Agricultural Trade. PhD Thesis, HU Berlin, Shaker Verlag

Abrar S., Morrisse O. and Rayner T., **2002,** Supply Response of Peasant Farmers in Ethiopia: A Farm –Level Profit Function Analysis, CREDIT Research Paper No. 02/16

Blignauta, J., Ueckermannb, L. and Aronson, J. 2009, Agriculture production's sensitivity to changes in climate in South Africa. South African Journal of Science 105.

El-Dukheri, Ibrahim (2007), Sudan Grain Market Study, Commissioned by WFP. Final Report (Draft), December 2007

Jechlitschka, K. und Lotze, H. (1997). Theorie und Anwendung eines Mehr-Markt-Modelles zur Sektoralen Analyse von Agrarpolitiken. *Zeitschrift für Agrarinformatik*

Helena Larsson, 1996, Relationships between rainfall and sorghum, millet and sesame in the Kassala Province, Eastern Sudan, Journal of Arid Environments (1996) 32: 211–223

Kirschke, D., Jechlitschka, K. (2002), Angewandte Mikroökonomie und Wirtschaftspolitik mit Excel. Lehr und Anleitungsbuch für computergestützte Analysen. München, Verlag Vahlen.

Mamingi, N., (1997), 'The Impact of Prices and Macroeconomic Policies on Agricultural Supply: A Synthesis of Available Results', *Agricultural Economics*, Vol. **16**, pp. 17–34.

Mendelsohn, R., Dinar, A. and Dalfelt, A. 2000. Climate change impacts on African agriculture, Yale University.

Palisade Corporation, (1997), *@Risk: Advanced Risk Analysis for Spreadsheets*. Palisade Corporation, Newfield.

Rockström, J., Folke, C., Gordon, L., Hatibu, N., Jewitt, G., Penning de Vries, F., Rwehumbiza, F., Sally, H., Savenije, H. and Schulze, R. (2004). A Watershed Approach to Upgrade Rainfed Agriculture in Water Scarce Regions through Water System Innovations: An Integrated Research Initiative on Water for Food and Rural Livelihoods in Balance with Ecosystem Functions. Physics and Chemistry of the Earth 29: 1109-1118.

Russell L. Lamb, 1999, Food Crops, Exports, and the Short-run PolicyResponse of Agriculture in Africa, Department of Agricultural and Resource Economics Campus Box 8109, North Carolina State University, Raleigh, NC 27695

Slingo, J.M., Challinor, A.J., Hiskins, B.J., Wheeler, T.R., 2005. Introduction: food crops in a changing climate. Philosophical Transactions of the Royal Society, Series B360, 1983–1989.

Thomas, D.S.G., Twyman, C., 2005. Equity and justice in climate change adaptation amongst natural-resource-dependent societies. Global Environmental Change, 15, 115–124

United Nations Environment Program and the World Trade Organization Trade and Climate Change, report, 2009 Printed by WTO Secretariat, Switzerland

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