IMPACT OF CLIMATE CHANGE AND INTERNATIONAL PRICES UNCERTAINTY ON THE SUDANESE SORGHUM MARKET: A STOCHASTIC APPROACH

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Summary

The paper simulates the possible sorghum price change and the related probability of occurrence under different rainfall scenarios and in a context of price uncertainty on international markets. The empirical investigation is based on the stochastic approach. Results underline an expected increase in sorghum price under the effect of the high level of uncertainty in precipitation and in international market price; the most intense likely change produced by the international market price of sorghum uncertainty; the need to overcome the agricultural view in policy making in order to include a market perspective.

Keywords: Climate change, Drought, Food prices, Stochastic approach, Sudan

JEL Classification codes: Q18, Q54

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1. Introduction

The paper, focusing on Sudan, aims at simulating the likely price change of the rain-fed agricultural commodity of sorghum according to different rainfall scenarios and taking into consideration the uncertainty of sorghum price on the international markets.

Climate change poses a serious and continuing threat to development in Sub-Saharan Africa (Scholes and Biggs, 2004; Jones and Thornton, 2003; Mendelsohn *et al.*, 2000) where many countries are seen as being highly vulnerable to weather variability and change (Slingo *et al.*, 2005). Rainfall patterns make Sudan the driest and most at risk country in Africa. Climate is characterized by extreme good or bad years more frequent than average years. Furthermore, precipitation, concentrated in a short growing season of around four months, shows a significant variability from the north, the desert area, to the centre, with dry and semi-dry climate, and to the south of the country, that is, the sub-tropical region (Zakieldeen, 2009; Frenken, 2005).

Rainfall supports the overwhelming majority of the Sudanese agricultural activities (Republic of Sudan, Ministry of Environment and Physical Development, 2007) that constitute the main economic sector of the country: in 2009, agriculture contributes to 93 percent of non-oil export revenues and employs 80 percent of the labour force in rural areas (Robinson, 2011). Almost all of the cultivated land, 95 percent, is under a rain-fed mechanized or rein fed traditional farming system, which grow more than 70 percent of the domestic cereal production, i.e. the primary staple food in the country (Government of Sudan, Ministry of Agricultural – Agricultural statistics). These features make rain-fed agriculture at the core of the country's food security issue, an important challenge in light of the 8.8 million individuals, or 22 percent of 43 million Sudanese, suffering from undernourishment (FAO, 2011).

Within cereals, sorghum is one of the major staple foods; its production is primarily consumed domestically and, according to the FAOSTAT food balance sheet, it contributes to 35 percent of the total average kilocalories per capita per day provided by grains.

The crop is predominantly produced in traditional and mechanized rain-fed farming systems at variable quantities depending mainly on the rainy season. The level of sorghum domestic production, which is affected by natural environment, usually determines the marketable surplus and domestic prices. According to the data provided by the Government of Sudan, Ministry of Agriculture, from 2007 to 2010, the average annual increase in sorghum price on the Sudanese domestic markets has been around 40 percent with severe consequences on food availability and access to food for households (SIFSIA and FAO, 2008). In the recent years, the increase in domestic price of sorghum has also followed the international market price, contributing to make the nature of sorghum price formation more complicated; both rainfall pattern and trend in price of sorghum on international markets are characterised by a high level of uncertainty and both make sorghum price on the Sudanese markets highly volatile and unpredictable.

In light of these considerations, the paper wants to give an answer to the following research question: What is the extent of the possible sorghum price change and the related probability of occurrence under different rainfall scenarios and are these variations more severely affected by the uncertainty on international markets? The answer is based on the evidence provided by a stochastic investigation referred to the Monte Carlo method (Hoffman, 1998; Metropolis and Ulam, 1949) where the stochastic variables are the annual changes of monthly mm of rainfall and the annual changes of monthly international market price of sorghum from 2002 to 2010.

The empirical study makes reference to the two major production markets of Gedaref, in eastern Sudan, and Obeid, in the western part of the country. In Sudan, markets run as auction for free trade sorghum that, according to the market regulations, is not allowed from being traded outside the auction fences. Gedaref is a major regional contributor to the national sorghum market supply. The surplus produced goes to other consuming areas either national or international (UN, 2003). All sorghum produced in Gedaref region is marketed through Gedaref auction. Obied is the main assembly wholesale market in north Kordofan, it is representative for the region and it is the linkage market between central, western and southern Sudan.

These two markets have been selected not only because of their importance and better organisation, but also because they show a different degree of vulnerability to climate change. While Kordofan is characterised by an acute vulnerability to extreme drought events, in Gedaref, the main sorghum surplus producer area of the country, the situation is less serious.

The paper contributes to the economic literature on climate change, agriculture and food security in Africa (Deaton, 1992; Molua, 2002; Watson *et al.*, 1997; Hassan, 2008; Dressa *et al.*, 2005; Dressa and Hassan, 2005; Mano and Nhmachena, 2006; Ouedraogo *et al.*, 2006; Blignauta *et al.*, 2009; Butt *et al.*, 2003; Ringler *et al.*, 2010), to the scant analysis on climate change and markets (Aker, 2008) and to those on price transmission (Minot, 2011; Sarris and Rapsomanikis, 2009; Gilbert and Morgan, 2010). However, several features distinguish this paper from these empirical investigations. First, the effect of rainfall changes on domestic sorghum price is analysed in combination with the impact of the international market price uncertainty. Second, the focus is on two different markets in the same country. This allows distinguishing the impact of drought from potentially confounding omitted variables (Aker, 2008). Third, the approach adopted overcomes the traditional time-series or panel data approaches that estimate sensitivity of agriculture or households to a change in rainfall. A time series analysis represents only a part of the empirical investigation. It is at the basis of the risk analysis that finds application to the specific topic for the first time in the literature.

The analysis developed also wants to contribute to the process of knowledge and understanding of the impact of climate change currently promoted in Sudan for its better integration in the national policy and planning system (Hassan, 2011).

The paper is organised as follows: Section 2 discusses the choice of the methodological approach and the steps in which the risk analysis is articulated. These latter represent the outline of the Sections from 3 to 5. More precisely, Section 3 introduces and estimates the parametric model, Section 4 defines the risk model and the simulations with this latter tested in Section 5. Section 6 concludes.

2. Methodology

The literature offers different approaches to the analysis of risk and uncertain outcomes. They can be classified in:

- Operation research (particularly, linear programming models) and game theoretic approaches;
- Sensitivity testing;
- Quantitative risk analysis.

The first category of approaches was prevailing in the 1960s and 1970s. It consists on the simple risk identification and in linking this risk with specific mitigation measures. The decision makers' preferences represent the selection criteria among different possible alternatives. For example, actions and events are organized according to a payoff matrix, a regret matrix, or a decision tree and actions are chosen on the assumption on the state of the "nature" to be as malevolent as possible. Typical criteria are maximin, minimax, maximum simple average. Other criteria ignore uncertainty altogether, such as the Laplace approach (Casavant *et al.*, 1999).

Due to their descriptive or prescriptive behaviour, these models represent the historical approach to uncertain outcomes; they were abandoned in favour of the sensitivity testing and risk analysis.

The former approach shows to what extent the viability of a project from the base-case (or the most probable scenario) is influenced by variations in major quantifiable variables. It consists on the identification of the key variables to which the project decision may be sensitive, the subjective quantification of likelihood of event occurrence and the seriousness of impact in that event.

Thus, sensitivity testing is a highly subjective technique based upon judgment rather than empirical evidence and uncertainty rather than risk. For example, it does not take into consideration the probability of occurrence of the events it models; the selection of the key variables depends on the specialist knowledge; and their variations make reference to standard percentages (Wills, 1987; Roucan-Kane *et al.*, 2009; Hoag, 2010).

These conceptual limitations are overcome by the quantitative risk analysis. This approach distinguishes between dependent or independent and certain or uncertain variables and estimates their correlation. The nature of the uncertainty is described by determining all the possible values a risky variable could take and the relative likelihood of each value, information that is summarized in a probability distribution function (Palisade Corporation, 2010). The output is represented by expected results, in terms of probability distributions of the possible values which could occur, and gives the decision maker a complete representation of all the likely outcomes (Casavant *et al.*, 1999).

Risk analysis is based on the Monte Carlo method (Kalos and Whitlock, 1986) (or Monte-Carlo random sampling) where the distribution of possible results (the probability distribution of the possible values which could occur) is generated recalculating "what if" over and over again, each time adopting a different set of randomly selected values, for the defined probability distributions (Palisade Corporation, 2010).

Undertaking a risk analysis requires more information than for sensitivity testing. It is based on empirical probability, that is on historical and/or experimental data. Due to the fact that in Sudan historical rainfall patterns data exists, it is possible to construct a probability of distribution such that price variability can be predicted in terms of expected values with associated levels of variability. The same holds true for the sorghum price on international markets.

The development of the risk model has followed five steps:

- Definition of the parametric model that explains annual changes of monthly price of sorghum;
- Estimation of the parameters of the previous model by means of an OLS approach;
- Generation of random inputs for rainfalls and international price of sorghum;
- Definition of alternative scenarios. The selected scenarios allow to compare a basic situation with a dry and a wet scenario in different contexts of international market price volatility;
- Evaluation of the stochastic model.

The likely price changes and their related probability are represented in the form of a cumulative density function. This latter describes the probability that a random change in domestic price of sorghum (*X*) with a given probability distribution will be found at a value less than or equal to *x*, that is:

$$F_X(x) = P(X \leq x) \qquad (1)$$

The right-hand side of the equation represents the probability that the random change in sorghum prices takes on a value less than or equal to *x*.

As the change in rain is a continuous variable, its probability density function is defined as follows:

$$F_X(x) = \int_{-\infty}^{x} f(t)\,dt \qquad (2)$$

This graphical representation has been preferred to the probability density function due to the problems associated to its use (see Hardaker *et al.*, 2004).

3. The parametric model

The tested log-log model makes reference to the following conceptual framework based on the literature, the seasonal calendar and interviews with Sudanese farmers.

The level of sorghum marketable surplus represents the main determinant of its price: it is function of the domestic production, particularly of households in rural areas (El-Dukheri, 2007).

For this reason, the first aspect taken into consideration is the annual change of the monthly production of sorghum (Q) specified as follows:

$$\Delta lnQ^{j}_{t,m} = \alpha + \beta\Delta ln\left(R^{j}_{t,m-9}\right) + \gamma\Delta ln\left(Pq^{j}_{t-2,m}\right) + \varepsilon \qquad (3)$$

where *ln* is the natural logarithm, *j* is the market (Obeid or Kordofan), *t* is the year, *m* is the month, with data starting from January, and $\Delta = \left(x_{t,m+12} - x_{t,m}\right)/x_{t,m}$ or $\Delta = \left(x_{t+1,m} - x_{t,m}\right)/x_{t,m}$. *R* is rainfall and is defined on the basis of the information provided by the seasonal calendar illustrated in Figure 1.

As the quantity produced is function of irrigation, form precipitation or artificial systems, starting from land preparation preceding the harvest season, rainfall is taken with a leg of 9 month: the dataset start with the data of April the previous year.

The model includes market incentives in the form of wholesale sorghum price, Pq, affecting farmers' production decision. As land preparation and planting are at the beginning of the year and market supply is between the end of the year and at the beginning of the next year, the variable has a lag of two years.

In order to better clarify equation (3), the first data of the model is for Q the change January 2004- January 2003, for R March 2003 – March 2002, and for Pq January 2002 – January 2001.

Figure 1 – Seasonal calendar for sorghum – Rain-fed and irrigated

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
		Dry season (Mar-Apr)		Hunger season (May-Aug)							
					Rainy season						
Major market supply (Nov-Apr)					Sowing and re-sowing (Jun-Aug)						Major market supply (Nov-Apr)
			Land preparation and planting (Apr-Jun)				First and second weeding (Aug-Sep)		Harvesting (Oct-Dec)		

Source: adapted from FewisNet and SIFSIA

Finally, $\alpha, \beta,$ and γ are the parameters to be estimated and ε is the error term.

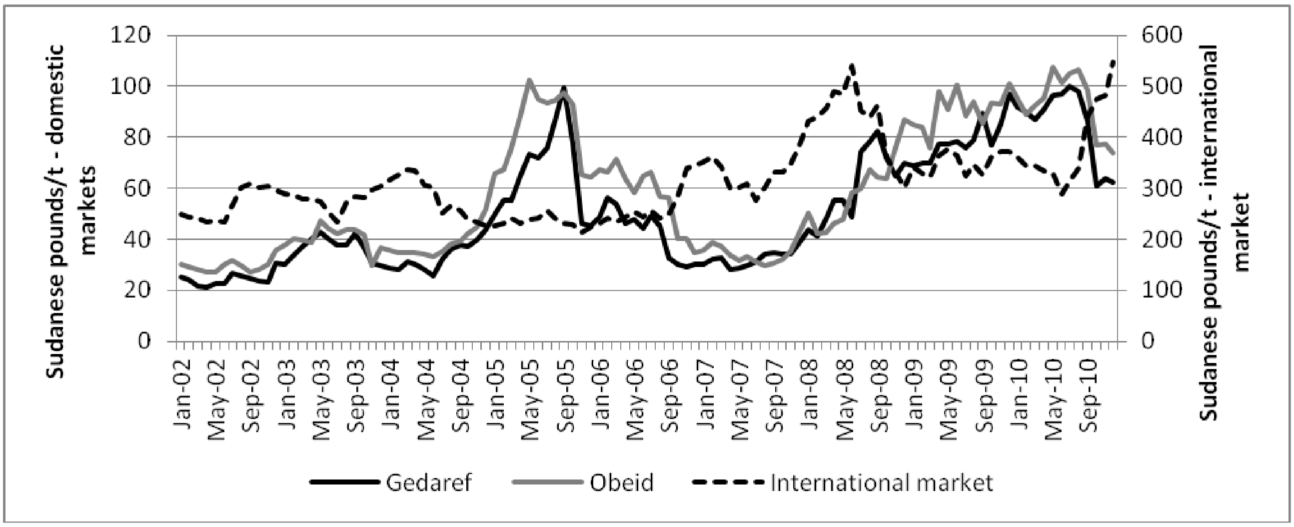
The annual change in monthly sorghum price (*Pw*) is specified as:

$$\Delta ln\left(Pw^{j}_{t,m}\right) = \alpha' + \beta'\Delta ln\left(Q^{j}_{t}\right) + \delta\Delta ln\left(PI_{t-1,m}\right) + \varepsilon' \qquad (4)$$

where *PI* is the international market price of sorghum. It has been introduced because, according to the literature, domestic and international markets of sorghum are highly integrated (SIFSA and FAO, 2008) and recent studies underline the role of the world market in setting domestic prices during the price surge of the first decade of the 2000s. Figure 2 verifies this aspect and shows that the price of sorghum on the analysed domestic markets follows the international price with a leg of one year, as assumed in equation (4).

High production and trade costs, and export flows are other internal factors affecting sorghum prices. They are not considered explicitly due to data unavailability. Also policies are not introduced in equation (3) not only because of data constraints, but also in the light of the literature suggesting that during the recent price surge they have been in favour of price stability (SIFSIA and FAO, 2008). It should also be underlined that sorghum is less controlled by government than other cash crops.

Figure 2 – Price of sorghum on Gedaref and Obeid markets and on the international market – monthly data 2001-2010 (Sudanese pounds/t)



Sources: Ministry of Agriculture Government of Sudan, Central Bank of Sudan and World Bank

The parametric model estimated is given by substituting equation (3) in equation (4). This has the following form:

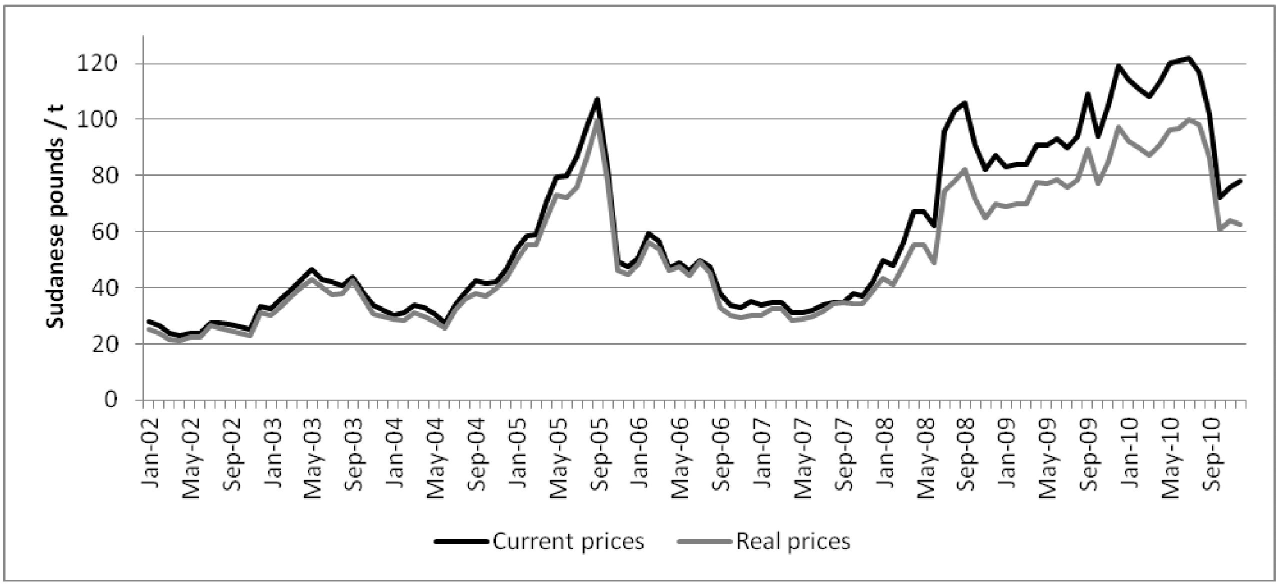
$$\Delta ln\left(Pw_{t,m}^{j}\right) = \alpha' + \beta\Delta ln\left(R_{t,m-9}^{j}\right) + \gamma\Delta ln\left(Pq_{t-2,m}^{j}\right) + \delta\,\Delta ln\left(PI_{t-1,m}\right) + \varepsilon' \quad (5)$$

with $\alpha', \beta, \gamma, and\ \delta$ the parameters to be estimated and ε' the error.

In the analysis, both *Pw* and *Pq* are the wholesale prices of sorghum in the two markets of Obeid and Gedaref provided by the Ministry of Agriculture of the Government of Sudan integrated by the GIEWS-FAO food price data. Literature suggests a high rate of inflation particularly during the recent years. Figure 4 and 5 confirm its important role beginning from 2008. On the contrary, the 2005 peak was due to the 2004/2005 low production as a consequence of a severe drought. For this reason, the monthly sorghum price time series has been taken in real terms. The current price has been deflated with the rate of inflation provided by the Central Bank of Sudan.

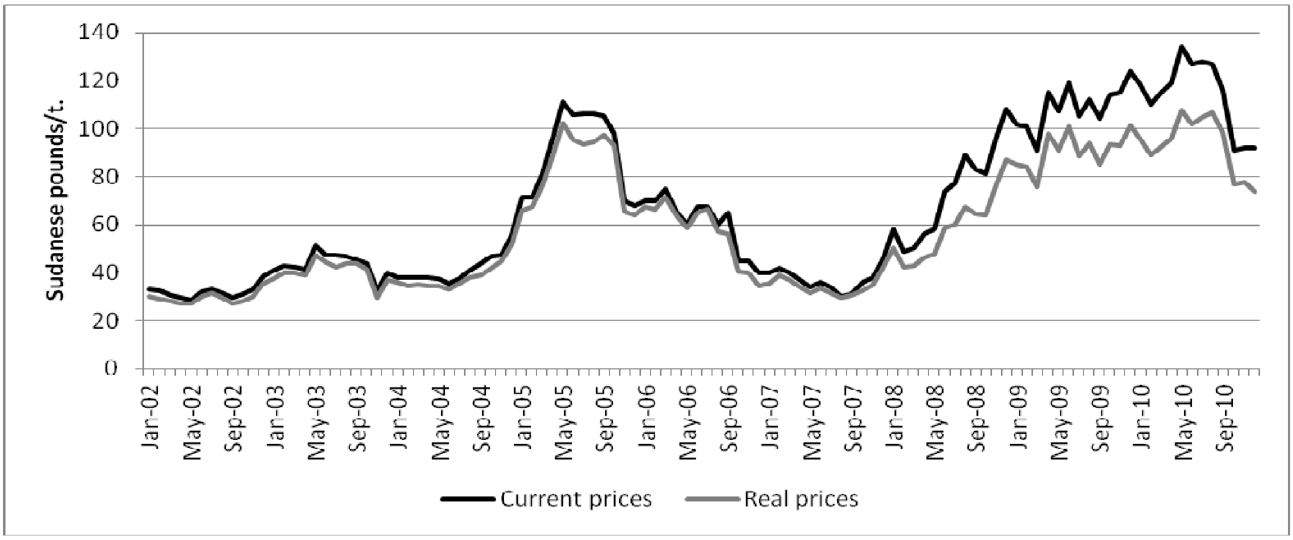
Rainfall data has been provided by the Arab Organization for Agricultural Development, whereas the international sorghum market price by the World Bank.

Figure 3 - Gedaref: sorghum price in current and real terms – monthly data – 2002-2010 (Sudanese pounds per 90 kg)



Source: Ministry of Agriculture Government of Sudan and Central Bank of Sudan

Figure 4 - Obeid: sorghum price in current and real terms monthly data – 2002-2010 (Sudanese pounds per 90 kg)



Source: Ministry of Agriculture Government of Sudan and Central Bank of Sudan

3.1. Regression model estimates

The model in equation (5) is estimated through an Ordinary last square (OLS) approach. Results are presented in Table 1.

Table 1 – OLS estimates of the parametric model - equation (5)

Market	Obeid	Gedaref
	a	b
α'	0.1040 (0.0363)	0.1117 (0.0139)
β $[\Delta ln(R^{j}_{t,m-9})]$	-0.0603 (0.0002)	-0.0069 (0.5905)
γ $[\Delta ln(Pq^{j}_{t-2,m})]$	-0.2597 (0.0100)	-0.5529 (<0.0001)
δ $[\Delta ln(PI_{t-1,m})]$	0.5434 (0.0141)	1.2884 (<0.0001)
Adjusted R-Square	0.2581	0.4104
F-statistic	10.3943 (<0.0001)	19.7962 (<0.0001)

(…) p-value

The tested model finds confirmation for Obeid (column a). The estimated coefficients are considerably close to their true values as suggested by the *p*-value and they also have the expected sign.

The change in sorghum price in the domestic market is more sensitive to a variation in its international price than in that of precipitation. The marginal contribution of a change in rainfall and market incentives to the dependent variable, holding the other variable fixed, is negative. At a reduction in precipitation, sorghum production and supply likely reduce and, assuming a constant demand, price increases; a similar consequence is expected at a reduction in market incentives in the form of *Pq*. On the contrary, the elasticity of changes in sorghum price to ΔPI is positive. It should be also noticed that, as indicated by the positive sign of the constant term, there are factors supporting the increase in sorghum price on the Obeid market independently by the explanatory variables.

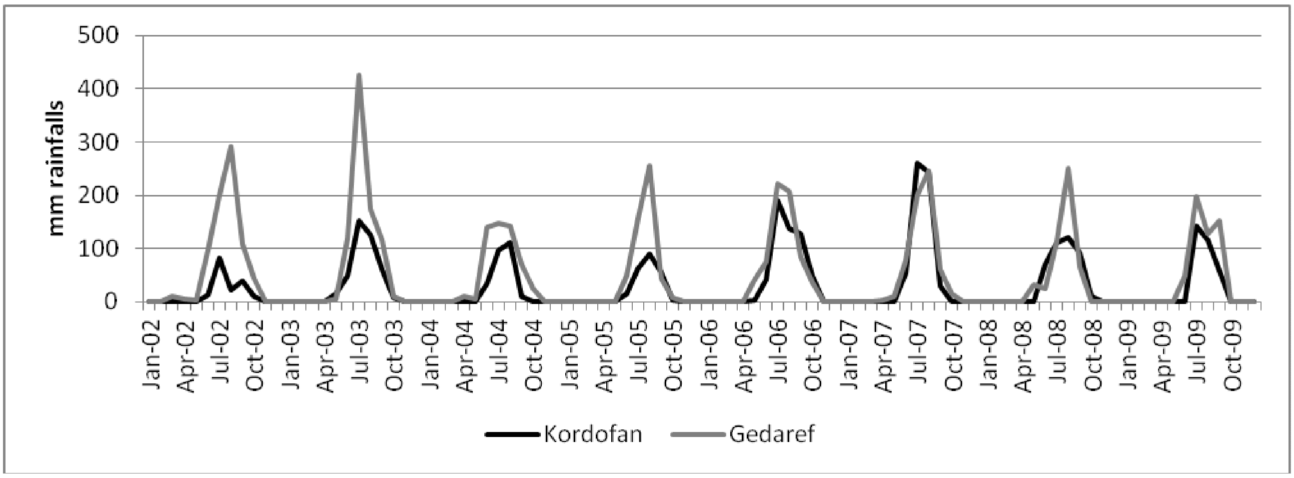
The regression explains around 26% of the total variation of the dependent variable and the overall significance of the regression model is good as suggested by the *F*-test and its probability.

The estimate for Gedaref differs from that of Obeid in two main elements. The first has to do with δ, an elasticity that is more than proportional for Gedaref and less for Obeid.

As previously underlined, Gedaref is a surplus area, producing not only for the domestic market but also for the international one. For this reason, Gedaref is more integrated into the international market than Kordofan whose production, often lacking due to weather conditions, is primarily consumed in the country.

Second, in the case of Gedaref rainfall is not statistically significant. As already mentioned, the less exposure of the region to extreme rainfall events, with respect to Kordofan, is one of the reasons. As illustrated in Figure 5, the amount and monthly length of rains in Kordofan is generally lower than in Gadaref.

Figure 5 – Rainfalls in Gadaref and Kordofan (mm) – monthly data (2002-2009)



Source: Arab Organization for Agricultural Development

In addition to this fact, there is the different role of rain-fed agriculture in the two regions.

As shown by Table 2, production from rain-fed agriculture dominates in both the areas taken into consideration, but Kordofan is primarily dependent on traditional rain-fed farming.

The system is conducted in small family units of 10 to 50 ha using greater levels of labour input and producing for both income and subsistence (Robinson, 2011). Its dependence on natural resources is greater than in the other two farming systems that have a greater incidence in Gedaref. In addition, in this region there is no traditional rain-fed sorghum production. The area is characterized by two farming systems:

- the historically low-input and low-output mechanized rain-fed and often semi-irrigated system, practised by individual large-scale business and companies; and
- the irrigated farming that represents a relatively new practice of sorghum production, even if it is more widespread than in Kordofan.

Table 2 - Sorghum: production ('000 tonnes)

	Irrigated		Mechanized rain-fed		Traditional rain-fed	
	Gedaref	Kordofan	Gedaref	Kordofan	Gedaref	Kordofan
1999/00	-	-	574	78	-	381
2000/01	-	-	495	44	-	106
2001/02	-	-	368	270	-	258
2002/03	-	-	473	127	-	232
2003/04	-	-	1176	148	-	207
2004/05	-	5	367	165	-	192
2005/06	85	4	765	265	-	277
2006/07	94	2	521	336	-	455
2007/08	80	3	429	127	-	441
2008/09	107	5	713	62	-	419
2009/10	49	1	192	138	-	282

Source: authors' calculation on Fao-GIEWS various years

4. The stochastic model

Results achieved in the previous section have suggested restricting the risk model to Obeid.

Rainfall and the international market price of sorghum are taken as a stochastic variable with the nature of its uncertainty described by a probability distribution. In other words, the expected change in sorghum price is evaluated under the hypothesis that the coming growing season will be affected by the whole distribution of the two stochastic variables that are reasonably assumed to be stochastically independent: the probability of one does not depend on the value taken by the other.

For the two distributions, rainfall and international sorghum price, the Maximum Likelihood Estimators (MLEs) technique is adopted to find a set of parameters that identifies a distribution that maximises the probability of obtaining the input data.

The different fits suggested by the software have been selected according to three statistic tests, the Chi-squared statistic (C-S), the Kolmogorov-Simirnov statistic (K-S), which does not require binning as the previous test, and the Anderson-Darling statistic (A-D), which does not require binning and instead of focusing on discrepancies in the middle of the distribution as the K-S statistic, it highlights differences between the tails of the fitted distribution and the input data. Table 3 and 4 illustrate the results for the three tests and the two stochastic variables.

According to the fit statistic tests, the better fit is the Normal probability distribution function for the international sorghum price dataset (K-S and A-D have the lowest values and C-S the second lowest value) and the Logistic probability distribution function for rainfall dataset (all the fit statistic tests have the smallest value).

Table 3 - Fit statistic tests input data: stochastic variable international sorghum price

Probability distribution function	Chi-squared statistic	Kolmogorov-Simirnov statistic	Anderson-Darling statistic
Triangular	5.5610	0.0938	0.6666
Normal	6.7805	0.0818	0.4977
Logistic	7.7561	0.0866	0.5189
Lognoramal	8.9756	0.0846	0.5480
InvGaussian	8.9756	0.0847	0.5522

Table 4 - Fit statistic tests input data: stochastic variable rainfall

Probability distribution Function	Chi-squared statistic	Kolmogorov-Simirnov statistic	Anderson-Darling statistic
Logistic	208.4878	0.2526	10.6952
Weobull	245.8049	0.2990	13.6758
Normal	256.2927	0.2982	13.1976
ExtValue	282.8780	0.3306	15.7075
Triangula	294.0976	0.3372	15.0721

The Logistic distribution function uses a continuous location parameter (the mean) equal to -0.0167 and a continuous scale parameter equal to 1.1831, while the normal distribution function is characterised by a mean of 0.0359 and a variance of 0.2387.

Starting from equation (5), on the basis of the two probability distribution functions and the parameters estimated with the OLS regression presented in Table 1, three stochastic models have been tested.

They represent the baseline scenario.

Model 1 sets:

$$\Delta ln\left(Pq^{j}_{t-2,m}\right) = 0 \;\; and \;\; \Delta ln\left(PI_{t-1,m}\right) = 0 \qquad (5.1)$$

In this case, the change in *Pw* is affected by likely values estimated for rainfall by the probability distribution function.

Model 2 is estimated assuming

$$\Delta ln\left(Pq^{j}_{t-2,m}\right) = 0 \;\; and \;\; \Delta ln\left(R^{j}_{t,m-9}\right) = 0 \qquad (5.2)$$

It allows verifying the likely impact of the international sorghum price change on *Pw*.

Finally, in Model 3 only

$$\Delta ln\left(Pq^{j}_{t-2,m}\right) = 0 \qquad (5.3)$$

and the likely change in *Pw* is affected by both the probability distribution function of rainfall and international sorghum prices taken into consideration.

Model 1 and 3 have been also estimated under different scenarios. The first is a "dry scenario" defined considering the projections made in the occasion of the Sudan's First National Communication to the UNFCCC and equal to a decrease of about 5 percent per month during the rainy season by 2060. The second simulation, the "wet scenario", takes into consideration an average annual increase of average monthly precipitations by the same amount.

According to the historical data for rainfall and the international market price of sorghum, on Obeid market model 3 suggests an expected average change in sorghum price by 12.45 percent with a 75.8 percent of probability for the change to be positive and 24.2 percent to be negative. Furthermore, there is a 70 percent of probability for this change to be included between 0 percent and 41 percent (Figure 6).

These values are affected more by the likely variation in the international market price of sorghum (PI) than in rainfall (R) as illustrated in Figure 7. Model 2 predicts an expected average increase in domestic price of sorghum on Obeid market by 12.35 percent against the 10.50 percent of Model 1 and, in both cases, there is an approximately 80 percent probability for the change to be positive.

Figure 6 – Baseline: probability distribution function for Model 3 (equation 5.3) – stochastic variables R and PI

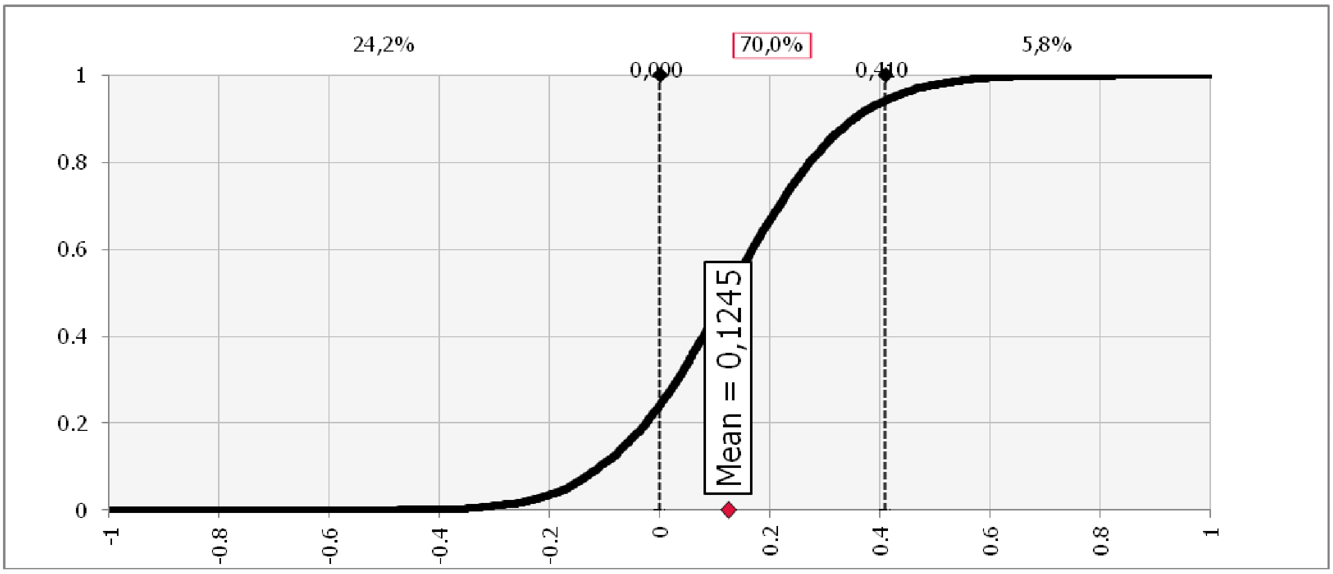
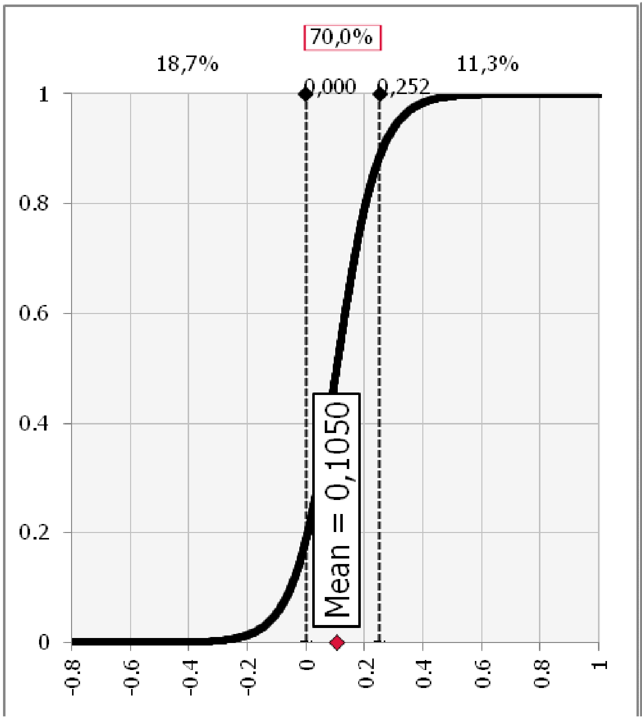


Figure 7 – Baseline: probability distribution function for Model 1 and 2 (equation 5.1 and 5.2)

a. Model 1 (stochastic variable R)



b. Model 2 (stochastic variable PI)

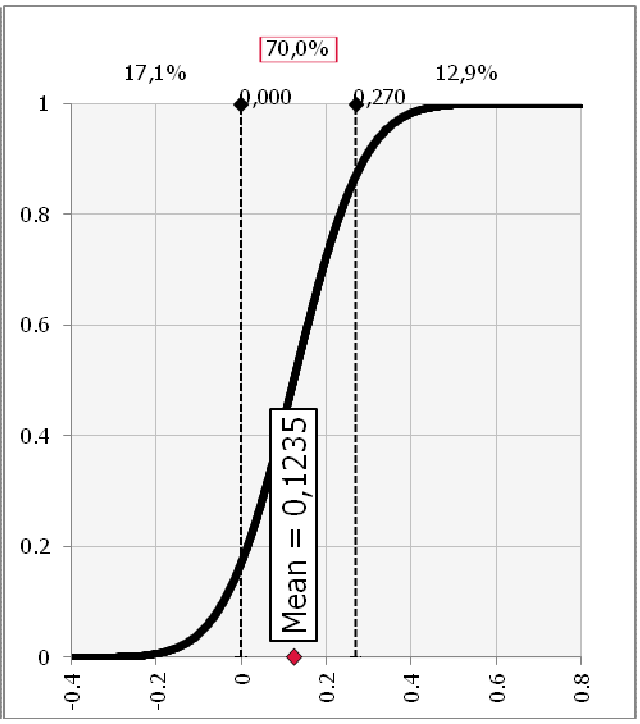


Table 2 compares the output of the stochastic models 1 and 3 in the baseline scenario with those of the dry and wet scenario.

Table 2 – Output of the stochastic model 1 and 3 by scenario

	Model 1			Model 3		
	Price change >0	Mean value	Upper delimiter* (prob. 70%)	Price change >0	Mean value	Upper delimiter* (prob. 70%)
Baseline	81.3	0.1050	0.252	75.8	0.1245	0.410
Dry scenario	85.1	0.1244	0.248	78.5	0.1440	0.389
Wet scenario	78.0	0.0903	0.265	73.5	0.1098	0.448

* The upper delimiter has been computed setting the lower delimiter equal to zero

As expected the mean values and the probability of a positive change in sorghum price increase under the assumption of a reduction in precipitation and vice versa in the case of better rainfall.

5. Conclusions

The analysis developed in this paper provides a stochastic investigation of the change in sorghum price on Gedaref and Kordofan markets according to different rainfall scenario suggesting an expected increase in prices under the effect of the high level of uncertainty in precipitation and in international market price. There is a high probability for sorghum price change to be as strong as it was from 2007 to 2010, which is around 40 percent with severe negative effects on access to food for poor households and their food insecurity situation (FAO and EU, 2011).

The possible magnitude of the expected change makes this analysis important for at least partly anticipating its negative consequences.

The OLS estimate of the parametric model, adopted for testing the elasticity of sorghum price changes to some relevant determinants, underlines the different explanatory capacity of rainfall according to the ecosystem and the agricultural system. Sorghum market in Kordofan, where serious drought episodes are frequent and the traditional rain-fed farming dominates, is particularly sensitive to precipitation than in Gedaref, where the crop is produced by mechanised, semi-irrigated and irrigated farmers and the ecosystem is less vulnerable to rainfall. This result supports the ecological zone approach to climate change adopted by Sudan with the National Adaptation Progamme of Action (Republic of Sudan, Ministry of Environment and Physical Development , 2007). The Government of Sudan identifies key adaptation needs in agriculture, water resource management and public health and recognises non-climatic factors contributing to vulnerability. They are: deep poverty levels; lack of income diversification; lack of agricultural inputs; resource mismanagement; land over-cultivation; fragile land and water resources; poor soil fertility; deforestation, natural resource conflicts; poor extension services; community displacement; and poor sanitation and health services. Thus, a specific focus is on the agricultural sector and its production factors. In light of the expected consequences related to the forecasted reduction in precipitation and increase in its uncertainty, in combination with a raise in temperature, this policy direction is important. Traditional farmers, strongly dependent on climate sensitive resources, dominate agriculture in drought prone areas and the coping strategies they have introduced in the face of climatic uncertainty are proving to be no longer effective (Zakieldeen, 2009; Republic of Sudan, Ministry of Environment and Physical Development, 2007). Recent analysis predicts in the region of Kordofan a decline of sorghum yield between 29 and 71 percent in the period 2030-2060 due to climatic change (Bashir Nimir and Elgizouli, 2011), supporting the evidence of a climate sensitivity analysis according to which some African countries will virtually lose their entire rain-fed agriculture by 2100 (Mendelsohn *et al.*, 2000).

However, results achieved by the developed empirical investigation suggest for sorghum the need to overcome this sectoral view to include a market perspective, that is to take into consideration also sorghum prices and demand. Rainfall is only one of the determinants of sorghum market prices. Markets for cereals are thin and very responsive to production changes (Teklu *et al.*, 1991) but if in the past the level of sorghum production and, as a consequence, its price were primarily determined by rainfall, today another important explanatory variable is represented by the international market price, despite the Sudanese feature of small open-economy. The risk analysis underlines that in Kordofan, in the baseline scenario, its expected impact on the domestic price of sorghum is greater than that produced by precipitation. The two expected average variations have a similar intensity only in the wet scenario.

The market perspective allows to better understand the link between sorghum production and food security and to introduce suitable policies. In Kordofan, for example, households are extremely vulnerable to food price shocks. From 60 to 65 percent of their total expenditure is on food items. Moreover, they are highly dependent on market as their main food source with percentages ranging from 80 to more than 90 percent (Robinson, 2011). In this context, supply side measures for achieving food security are not enough; a combination of well coordinated interventions is required, including macroeconomic policies for the management of the pass-through of price from international to the local markets.

Results achieved from the risk analysis suggest an expected average increase in sorghum prices also in the wet scenario. In this case, however, the rise in mean value is less intense than in the baseline and suggests the importance of investing in research and development and of promoting measures aimed at the introduction of water harvesting techniques, low-technology forms of water harvesting and conservation and drought resistant seed varieties. In addition, it should be evaluated the possibility to allow the irrigated farming system to expand in sorghum production. In fact, the irrigated sector, made up of small to medium-scale mechanised, commercial farms on large scale, gravity-fed scheme, almost all government owned, has a low incidence in sorghum production due to the fact that it is mostly released, form tenancy restriction and obligations, to grow cotton (Robinson, 2011).

A final observation relates to the parametric model estimated particularly for Kordofan. The independent variables taken into consideration explain only part (less than one quarter) of the total sorghum price change as underlined by the adjusted R-squared. This aspect suggests the need for further investigation in order to better understand the determinants of the sorghum market tendencies and the role of drought.

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