Weather index-based insurance in a cash crop regulated sector: ex ante evaluation for cotton producers in Cameroon

Antoine Leblois*, Philippe Quirion† and Benjamin Sultan‡

December 2012

Abstract

In the Sudano-sahelian zone, which includes Northern Cameroon, the inter-annual variability of the rainy season is high and irrigation is scarce. As a consequence, bad rainy seasons have a massive impact on crop yield. Traditional insurances, which would mitigate such impact, suffer from asymmetric information. They are based on crop damage assessment leading to high transaction costs compared to the value of production. Moreover the important spatial variability of weather creates a room for pooling the impact of bad weather using index-based insurance products. We assess the risk mitigation capacity of weather index-based insurance for cotton growers. We compare the capacity of various indices, mainly based on daily rainfall, coming from different sources to increase the expected utility of a representative risk-averse farmer.

We first give a tractable definition of basis risk and use it to show that weather index-based insurance is associated with large basis risk. It thus has limited potential for income smoothing (in accordance with previous results in Niger), whatever the index or the expected utility function is chosen. Using observed cotton sowing dates significantly decreases the basis risk of indices based on daily rainfall data. Second, in accordance with the existing agronomical literature we found that the length of the cotton growing cycle is the best performing index considered. Third, cutting the Cameroonian cotton zone into more homogeneous rainfall zone seems necessary to limit subsidisation of the driest zones. As a conclusion, we found very low gains to implementing an index insurance for cotton growers in Northern Cameroon: about 1% of certain equivalent income with standard utility functions. This is low, especially when compared to the price hedging (against seasonal variability of international prices) of the national cotton company by fixing cotton purchasing price before sowing. Such results could help for the design of an insurance for the zones for which production is heavily depending on meteorological factors, but also to take into account other determinants of profit variations, such as the cotton purchasing price.

Keywords: Agriculture, index-based insurance.
JEL Codes: O12, Q12, Q18.

---

[*] CIRED (Centre International de Recherche sur l'Environnement et le Développement), leblois@centre-cired.fr.

[†] CIRED, LMD (Laboratoire de Météorologie Dynamique).

[‡] LOCEAN (Laboratoire d'Océanographie et du Climat, Experimentation et Approches Numériques).

Contents

1 Introduction

Seed-cotton is the major cash crop of Cameroon and represents the major income source, monetary income in particular, for growers of the two northern provinces: *Nord* and

Extrême Nord according to Folefack et al. (2011). It is grown by smallholders with about .6 hectares per farmers dedicated to cotton production on average in the whole area (Gergerly, 2009). 346 661 growers cultivated 231 993 ha in 2005 reaching its peak, while, in 2010, the number of grower has dropped to 206 123 growers and the area cultivated with cotton shrank to 142 912 ha.

Cotton is rainfed in almost all sub Saharan African (SSA) producing countries, and largely depends on rainfall availability. The impact of a potential modification of rainfall distribution during the season or the reduction of its length has been found as of particular importance (cf. section 3.1) and could even be higher with an increased variability of rainfall (ICAC, 2007 and 2009) that is supposed to occur under global warming (IPCC, 2007). Moreover the sector also suffers from several geographic and climatic challenges: isolation of the North of the country and decline in soil fertility due to increasing land pressure.

When growers are not able to reimburse their input credit at the harvest[1], they are not allowed to take a credit the next year. Falling into a situation of unpaid debt is thus very painful for those cotton growers (Folefack et al., 2011).

Traditional agricultural insurance, based on damage assessment cannot efficiently shelter farmers from such issues because they suffer from an information asymmetry between the farmer and the insurer, creating moral hazard, and and necessiting costly damage assessment. An emerging alternative is insurance based on a weather index, which is used as a proxy for crop yield (Berg et al., 2009). In such a scheme, the farmer, in a given geographic area, pays an insurance premium every year, and receives an indemnity if the weather index of this area falls below a determined level (the strike). Weather index-based insurance (WII) does not suffer from the two shortcomings mentioned above: the weather index provides an objective, and relatively inexpensive, proxy of crop damages. However, its weakness is the basis risk, i.e., the imperfect correlation between the weather index and the yields of farmers contracting the insurance. The basis risk can be considered as the sum of three risks: first, the risk resulting from the index not being a perfect predictor of yield in general (the model basis risk). Second, the spatial basis risk: the index may not capture the weather effectively experienced by the farmer; all the more so if the farmer is far from the weather station(s) that provide data on which index is calculated. Third, the heterogeneities among farmers, for instance due to their practices or soil conditions are often found to be high in developing countries.

A recent but prolific literature emerged about rainfall insurance in low income countries, analysing the impact of pilots trough ex post studies. The most robust finding about index insurance is the low take up rate that is explained by price and budget elasticity (Karlan et al., 2012 and Mobarak and Rosenzweig, 2012) as well as by non-price frictions such as marketing, framing and trust (Cole et al., 2012), social networks or the provision

---

[1] The standing crop is used as the only collateral and credit reimbursement is deducted from growers' revenue when the national company buys the cotton, cf. section 2.2 for further descriptions.

of financial literacy on insurance (Cai, 2012, Giné et al., 2012). Building on the the idea of Clarke (2011) showing that in the presence of risk aversion, basis risk could simply explain low WII take up, we will look at the maximum potential gain cotton growers could gain from index insurance.

This paper therefore aims at assessing WII contracts in order to shelter cotton growers against drought risk (either defined on the basis of rainfall, air temperature or satellite imagery). Insurance indemnities are triggered by low values of the index supposed to explain yield variation. Insurance allows to pool risk across time and space in order to limit the impact of meteorological (and only meteorological) shocks on producers income.

The first section describes the cotton sector in Cameroon while the second one is dedicated to describing the data and methods including agrometeorological methods used for index design and the insurance policy contract and model calibrations. In the last section we present the results before concluding.

2 Area and data

2.1 Study area and institutional setting

The cotton administration counts 9 regions divided in 38 administrative Sectors (Sadou et al., 2007, cf. Figure 2).

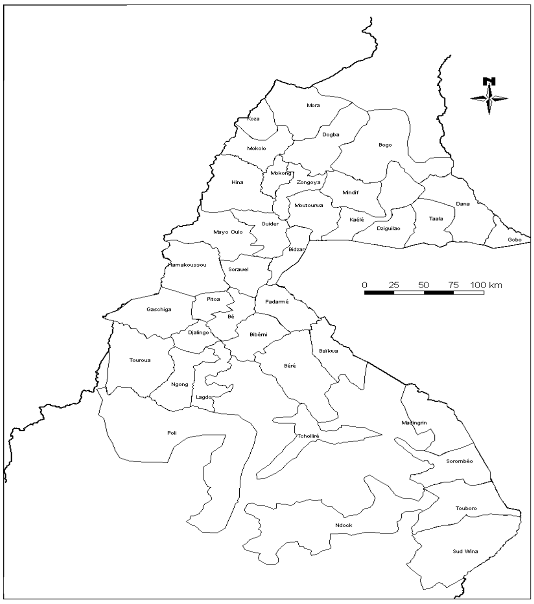

Figure 1: Sodecoton's administrative zoning: the Sectors level.

2.1.1 Purchasing price fixation

The cotton society (Sodecoton) and its Malian (CMDT) counterpart, are still public monopsonies (Delpeuch and Leblois, forthcoming). Those parastatals are thus the only agent in each country to buy cotton from producers at pan-seasonally and -territorially fixed price, varying marginally depending on cotton quality at harvest.

As already mentioned by Mayayenda and Hugon (2003), Makdissi and Wodon (2004), Boussard et al. (2007) and Fontaine and Sindzingre (1991) such stabilisation has an impact on production decisions since it insures producers against intra-seasonal variations of the international cotton price by guaranteeing the announced price.

Moreover, the the producers' organization (OPCC) already has recently played part of a risk pooling role (or more precisely inter-annual producers' income smoothing) when reallocating the annual surplus of good years into a compensation found for bad years through a stabilisation fund. Before that the surplus was simply distributed as a premium to producers for the next growing season (Gergely, 2009). Besides, the the producers' organisation also urge the villages to stock cereals in order to increase consumption smoothing and to lower the risk of decapitalization in case of a negative income shock (Kaminsky et al., 2011).

2.1.2 Input credit scheme

The specificity of those institutional setting is also characterized by the input provision at the 'filière' level. Costly inputs are indeed provided on credit by the national companies at sowing, ensuring a minimum quality and their availability in spite of a great cash constraint that characterize the lean season in those remote areas: the so-called 'hunger gap'. Inputs are distributed at the sowing and reimbursed, in kind, the potential harvest being the only collateral.

Collective guarantee circles (CGC, named *Groupe d'Initiative Commune* in French: *GIC*'s) were set up to control the risk of bad management in large groups, hence creating a new associative layer within the village: the producers' groups (PGs) (Enam et al., 2011). There is about 2000 active PGs in 2011, which represent an average of about 55 PGs per Sector. However, in spite of a self-selection process to form those groups, the mechanism suffers from many institutional issues, as described in Kaminsky et al. (2011). The group indeed put up bond for each grower, this lead the large growers to be more responsible, since they have a larger collateral.

2.2 Data

Yield and gross margin per hectare are available at the Sector level from 1977 to 2010, provided by the Sodecoton. Gross margin is the difference between the value of cotton sold and the value of purchased inputs: fertilisers, pesticides, but not labor since the vast

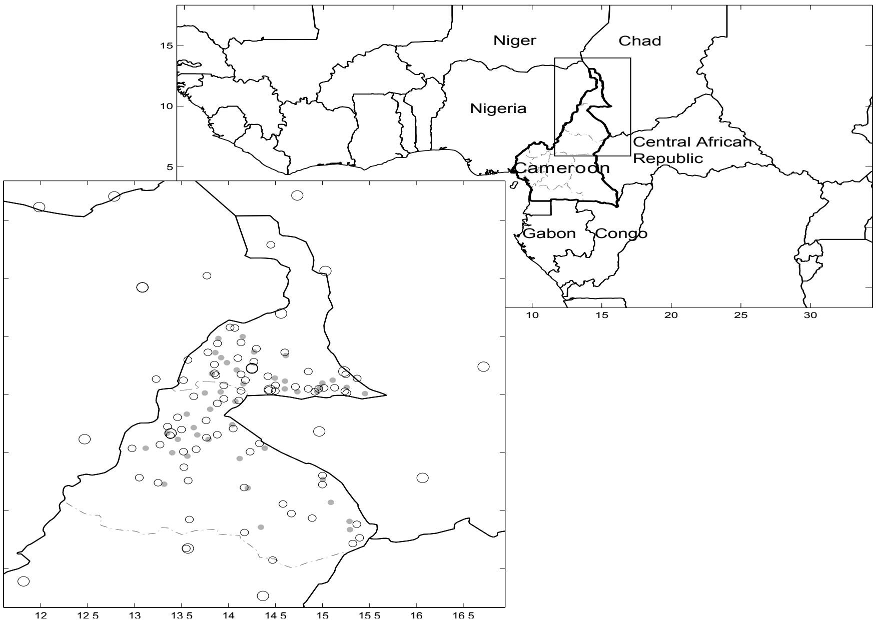

Figure 2: Network of meteorological stations (large black circles) and rainfall stations (small black circles) of the region and barycentres of Sectors (grey dots: average of PGs locations). Sources: Sodecoton, IRD and GHCN (NOAA).

majority of workers are self-employed. We will call it cotton profit thereafter.

We matched this data to a unique meteorological dataset which we have build. It includes daily rainfall and temperatures (minimum, maximum and average) coming from different sources[2], with at least one rainfall station per Sector (Figure 3). Sectors' agronomical data are matched to rainfall data using the nearest station, that is, at an average distance of 10 km and a maximum distance of 20 km. Sectors' location are the average GPS coordinates of every Sodecoton's producers group (PG) within the Sector. A Sector represents about 900 square kilometres (cf. Figure 1).

We interpolated, for each Sector, temperature data from ten IRD and Global Historical Climatology Network (GHCN) synoptic meteorological stations of the region: six in Cameroon and four in Chad and Nigeria[3]. We used a simple Inverse Distance Weighting interpolation technique[4], each station being weighted by the inverse of its squared distance to the Sector considered applying a reduction proportional to 6.5 degree Celsius (°C) per 1000 meters altitude. The average annual cumulative rainfall over the whole producing zone is about 950 millimetres (mm) as showed in Table 1, hiding regional heterogeneities we explore in the next section. The profit series suffer from a high attrition rate before 1991, with about one third of missing data, but limited between 1991 and 2010 (18%).

---

[2] *Institut de la Recherche pour le Développement* (IRD) and Sodecoton's high density network of rain gauges.

[3] National Oceanic and Atmospheric Administration (NOAA), available at: www7.ncdc.noaa.gov

[4] IDW method (Shephard 1968), with a power parameter of two.

Moreover, the collapse of the cotton sector occuring since 2005 caused a strong decrease in yield from that date, we will thus focus in our results on the 1991-2004 sub-period, for which we observe similar summary statistics.

Table 1: Yield and rainfall data summary statistics

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
Annual cumulative rainfall (mm)	950	227	412	1 790	849
Yield	1 150	318	352	2352	849
Cotton profit* (CFA francs per ha)	114 847	50 066	-7 400	294 900	849
1991-2004 sub-period					
Annual cumulative rainfall (mm)	953	211	491	1 708	479
Yield	1 202	297	414	2 117	479
Cotton profit* (CFA francs per ha)	134 323	50 542	4 838	294 900	479

* Profit for one hectare of cotton after input reimbursement, excluding labor.

We finally used the Normalized Difference Vegetation Index (NDVI), available for a 25 year period spanning from 1981 to 2006 at 8 km spatial resolution[5]. This vegetation index is a relative measure of the spectral difference between visible (red) and near-infrared regions and is thus directly related to green plants biomass.

3 Methods

3.1 Weather and vegetation indices

3.1.1 Weather indices and cotton growing in Cameroon

The critical role of meteorological factors in cotton growing in Western and Central Africa has been widely documented. For instance, Blanc et al. (2008) pointed out the impact of the distribution and schedule of precipitation during the cotton growing season on long run yield plot observations in Mali. In recent studies on this region of the world, length of the rainy season, and by extension late onset or premature end of the rainy season, are also seen as key elements determining cotton yields. The onset and duration of the rainy season were recently found to be the major drivers of year-to-year and spatial variability of yields in the Cameroonian cotton zone (Sultan et al., 2010). Luo (2011) finally reports many results of the literature about the impact of temperatures on cotton growth that seem to depend on the cultivar: cotton is indeed grown in some very hot region of the world, such as in Ouzbekistan.

3.1.2 Designing rainfall indices

We first considered the cumulative rainfall (CR) over the whole rain season. We define and only consider significant daily rainfall, that will not be entirely evaporated, as superior

---

[5] The NOAA (GIMMS-AVRHH) remote sensing data are available online at: www.glcf.umd.edu/data/gimms), Pinzon et al. (2005).

to .85 mm following the meteorological analysis of Odekunle (2004). We then consider a refinement (referred to as BCR) of each of those simple indices by bounding daily rainfall at 30 mm, corresponding to water that is not used by the crop due to excessive runoff (Baron et al., 2005). We will thus mainly study the length of the growing season (GS), cumulative (significant) rainfall (CR) and the bounded cumulative rainfall (BCR, described in the previous section) on the whole growing season and by growing phases.

Only considering critical rainfall used by the crop, requires the availability of growing cycle dates (typically the sowing or emergence date). Moreover, as shown by Marteau et al. (2011), a late sowing can have dramatical impact on harvest quantity. We used the informations about sowing date reported by the Sodecoton in their reports: the share of the acreage sowed with cotton at each of every 10 days between the 20 of may until the end July. We defined the beginning of the season (the emergence) as the date for which half the cotton area is already sown (has already emerged).

We also simulated a sowing date following a criterion of the onset of the rainfall season defined by Sivakumar (1988). It is based on the timing and of first rainfall's daily occurrence and validated by Sultan et al. (2010) and Bella-Medjo (2009) on the same data. We will test whether observing the date of the growing cycle, could be useful to weather insurance by using both the raw and approximated date of sowing and emergence. Simulated sowing date seemed to perform well for the same type of insurance contract in the case of millet in Niger, as shown by Leblois et al. (2011).

We compare two growth phase schedules: the observed one is referred to as *obs* and the one simulated is referred to as *sim* in the paper. The onset of the simulated growing season is triggered by a rainfall zone specific threshold in cumulation of significant rainfall (50 mm during 5 days), the offset is the last day with observed significant rainfall.

We have designed more complicated indices, described in the annex A. They are not discussed in the results since they were not performing better than the rather simple indices considered.

3.2 Weather index-based insurance set up

3.2.1 Indemnity schedule

In this section we simulate the impact of an insurance based on weather indices used to pool yield risk across Sectors. The indemnity is a step-wise linear function of the index with 3 parameters: the strike (S), i.e. the threshold triggering indemnity; the maximum indemnity (M) and λ, the slope-related parameter. When λ equals one, the indemnity is either M (when the index falls below the strike level) or 0. The strike represents the level at which the meteorological factor becomes limiting. We thus have the following indemnification function depending on x, the meteorological index realisation:

$$I(S, M, \lambda, x) = \begin{cases} M, & \text{if } x \leq \lambda.S \\ \frac{S-x}{S\times(1-\lambda)}, & \text{if } \lambda.S < x < S \\ 0, & \text{if } x \geq S \end{cases} \tag{1}$$

It is a standard contract scheme of the WII literature. The insurer reimburse the difference between the usual income level and the estimated loss in yield, yield being proxied by the meteorological index realization.

3.2.2 Insurance policy optimization

We use different objective function and show that our results are robust to such choice. We consider the three following objective function, respectively mean-absolute semi-deviation (MASD, Konno and Yamazaki, 1991; in the vein of Markovitz' mean-absolute deviation model but only considering downside risk, equation 2), a constant absolute risk aversion (CRRA) utility function (equation 3) and finally a negative exponential, i.e. constant relative risk aversion (CRRA) utility function (equation 4). Expected utility are expressed as follows:

$$U_{MASD}(\tilde{\Pi}) = E(\tilde{\Pi}) - \phi \times \frac{1}{N} \sum_{i=1}^{N} \Big(\max\big(E(\tilde{\Pi}) - \Pi_i, 0\big) \Big), \qquad \tilde{\Pi} = \{\Pi_1, ..., \Pi_N\} \tag{2}$$

$$U_{CARA}(\Pi_i) = \Big(1 - \exp\big(-\psi \times (\Pi_i + w)\big)\Big) \tag{3}$$

$$U_{CRRA}(\Pi_i) = \frac{(\Pi_i + w)^{(1-\rho)}}{(1-\rho)} \tag{4}$$

$\tilde{\Pi}$ is the vector of cotton profit within the period and among the Sectors considered, N the number of observations, and w other farm and non-farm income. ϕ, ρ and ψ are respectively the risk aversion parameter in each objective function. Risk aversion is equivalent to inequality aversion in this context, since we consider the production function to be ergodic and assimilated spatial (Sectoral) variations to time variations.

We maximised the expected utility of these three utility functions and computed the risk premium, i.e. the second term of the first objective function and the expected income minus its certainty equivalent in the two latter, for each of them. The first function is simply capturing the income 'downside' variability (i.e. variations are considered only when yield is inferior to the average yield considered to be particularly harmful). The second term represents the average downside loss, loss being defined as yield inferior to average of yield distribution among the calibration sample. It represents about 1/3 of average yield with very little change when considering different samples.

The second and third objective functions are quite standard in the economic literature; we added an initial income level, following Gray et al. (2004). Initial income is fixed to the average revenue of one hectare of cotton, after input reimbursement (cf. section, the fixed cost of indemnification is about one day of rural wage.

Given that we use the aversion to wealth in both case (as opposed to transitory income), we assume that $\psi = \rho/W$, with W the total wealth, according to Lien and Hardaker (2001). The insured profit (Π^I) is the observed profit minus premium plus the hypothetical indemnity:

$$\Pi_i^I = \Pi(x) - P(S^*, M^*, \lambda^*, x) + I(S^*, M^*, \lambda^*, x) \tag{5}$$

The loading factor is defined as a percentage of total indemnifications on the whole period (β, fixed at 10% of total indemnification), plus a transaction cost (C) for each indemnification, fixed exogenously to one percent of the average yield.

$$P = \frac{1}{N}\big[(1+\beta) \times \sum_{i=1}^{N} I_i\big(S^*, M^*, \lambda^*, x_i\big) + C \times \sum_{i=1}^{N} F_i\big], \text{ with } F_i = \begin{cases} 1 \text{ if } I_i > 0 \\ 0 \text{ if } I_i = 0 \end{cases} \tag{6}$$

We finally optimize the three insurance parameters in order to maximise utility and look at the reduction in the risk premium depending on the index and the calibration sample. The strike is bounded by a maximum indemnification rate of 25%.

3.3 Model calibration

3.3.1 Initial wealth

We use three surveys ran by Sodecoton in order to follow and evaluate growers' agronomical practices. They respectively cover the 2003-2004, 2006-2007 and 2009-2010 growing seasons. We also use recall data for the 2007 and 2008 growing season from the last survey. The localizations of surveyed clusters (as displayed in Figure 7, in the Appendix) are distributed across the whole zone. We computed the share of cotton-related income in on-farm income for 5 growing seasons. Cotton is valorized at the average annual purchasing price of the Sodecoton and the production of major crops (cotton, traditional and elaborated cultivars of sorghos, groundnut, maize, cowpea) at their annual Sector level price observed at the end of the lean season period, corresponding to April of the next year. The lower level of observation (especially for recall data) is explained by the year by year crop rotation that make farmers with low surface grow cotton only one year each two years. We can however not exclude that recall is not perfect and that some missing data remains.

As showed in Table 2 the share of cotton in on-farm income of cotton growers is more than 45% in average. There are however some limits to that calibration, for instance

Table 2: On-farm and cotton income of cotton producers during the 2003-2010 period (in thousands of CFA francs)

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
2003					
On-farm income	545.493	539.744	.587	6049.995	1439
Cotton share of income (%)	**49.8**	1.80	.5	100	1439
2006					
On-farm income	493.395	496.589	43.111	3845.007	850
Cotton share of income (%)	**42.4**	17.1	4	100	850
2008*					
On-farm income	472.656	490.784	18.390	4050.643	811
Cotton share of income (%)	**65.8**	21.7	10.6	100	811
2009*					
On-farm income	802.533	866.899	22.932	9520.681	952
Cotton share of income (%)	**40.9**	20.6	4.6	100	952
2010					
On-farm income	699.728	759.979	34.451	9236.930	1138
Cotton share of income (%)	**31.7**	24	0.3	100	1138
Whole sample					
On-farm income	606.546	661.703	.587	9520.681	5190
Cotton income	246.064	278.751	.185	4525.1	5190
Cotton share of income (%)	**45.5**	23.1	.3	100	5190

Source: Sodecoton's surveys and author's calculations.

* Recall data from the 2010 survey.

the period is not representative from the period studied in the article since this period, as already mentioned, the cotton production collapsed after 2004, especially due to low incentive (high fertiliser prices). We finally fixed average on-farm income as the double of average cotton income of our sample. We also tested on-farm income increasing in function of cotton income[6], by estimating the relation between both variables on the same surveys, but it did not modify the results and did not make insurance more attractive.

3.3.2 Risk aversion

We used a field work (Nov. and Dec. 2011) to calibrate the risk aversion parameter of the CRRA function. We assumed the CRRA preferences in that section because it is standard in such field work, but, as said previously, the two other parameters can be inferred from the level of the calibrated relative risk aversion.

A survey was implemented in 6 sodecoton groups of producers in 6 different locations, each in one region, out of the nine administrative regions of the Sodecoton, two in each

---

[6] For three major reasons it can be assumed that cotton yields and other incomes (mainly other crops yields) are being correlated. First, even if each crop has its own specific growing period, a good year for cotton in terms of rainfall is probably also a good rainy season for other crops growing during the rainy season. Second, a household that have a lot of farming capital is probably able to get better yields in average for all crops. Third, cotton being the main channel to get quality fertilisers, the higher is the cotton related input credit, the higher the collateral.

agro-ecological areas[7], were about 15 cotton growers were randomly selected[8] to answer a survey concerning socio-economic variables, crop cultivated and yields, technical agronomic practices and agro-meteorological assessment, such as the sowing date choice and the criteria for this choice. Those producers were asked to come back at the end of the survey and lottery games were played. We use a typical Holt and Laury (2002) lottery, apart from the fact that we do not ask for a switching point but ask a choice between two lotteries (one risky and one safe) for a given probability of the bad outcome. It thus allows the respondent to show inconsistent choices, and if not, ensures that she/he understood the framework.

At each step (5 lottery choices displayed in Table 3) the farmers have to choose between a safe (I) and a risky (II) situation, both constituted of two options, represented by a schematic representation of realistic cotton production in good and bad years. The gains represent the approximative average yield (in kg) for 1/4 of an hectare, the unit historically used by all farmers and Sodecoton for input credit, plot management informal wages, etc. The gains were displayed in a very simple and schematic way in order to fit potentially low ability of some farmers to read and to understand a chart, given the low average educational attainment in the population. For each lottery, the options are associated with different average gains, probabilities were represented by a bucket and ten balls (red for a bad harvest and black for a good harvest). When all participants made their choice, the realization of the outcome (good vs. bad harvest) is randomly drawn by childrens of the village or a voluntary lottery player picking one ball out of the bucket.

The games were played and actual gains were offered at the end. Players were informed at the beginning of the play that they will earn between 500 and 1500 CFAF francs, 1000 CFAF representing one day of legal minimum wage. We began with the lotteries in which the safer option was more interesting. Each lottery was then increasing the relative interest of the risky option. We thus can compute the risk aversion level (ρ) using to the switching point (or the absence of switching point) from the safe to the risky option, assuming CRRA preferences. They are displayed in Table 3, BB goes for black balls and RB for red balls.

---

[7] The localization of those six villages are displayed in Figure 8 in the Appendix.

[8] Randomly taken out of an exhaustive list of cotton growers detained by the Sodecoton operator in each village in order to manage input distribution each year. Those groups of producers are all about the same size because they are formed by the Sodecoton in order to meet management requirement. Villages are divide into 2 groups when there is too numerous producers in one single village and alternatively villages are put together in the same group when they are too small.

Table 3: Lotteries options

	I		**II**				
Number of BB (prob. of a good outcome)	RB	BB	RB	BB	Difference (II-I) of expected gains	Risk aversion (CRRA) when switching from I to II	Risk aversion (MASD) when switching from I to II
5/10	150	250	50	350	0	≤ 0	≤ 0
6/10	150	250	50	350	20	]0,0.3512]	]0,0.17]
7/10	150	250	50	350	40	]0.3512,0.7236]	]0.17,.29]
8/10	150	250	50	350	60	]0.7236,1.1643]	].29,.38]
9/10	150	250	50	350	80	]1.1643,1.7681]	].38,.44]
No risky option chosen						> 1.7681	>0.44

4 Results

4.1 Risk aversion distribution

We dropped each respondent that showed an inconsistent choice[9] among the set of independent lottery choices representing 20% of the sample: 16 individuals on 80. We choose the average of each interval extremities as an approximation for ρ, as it is done in the underlying literature. Table 10 in the appendix shows the summary statistics of the obtained parameters in the whole sample and in each villages. We display the distribution of the individual relative risk aversion parameter across the 6 villages in Figure 3.

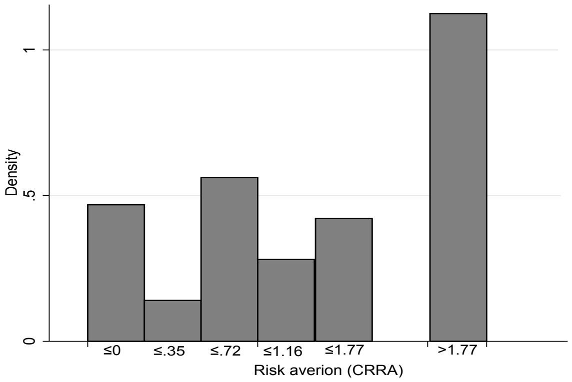

Figure 3: Distribution of relative risk aversion (CRRA) parameter density (N=64).

According to the previous methodology (described in section 3.3.2) 20% of our sample (N=64) show a risk aversion below or equal to .72, and 38% a risk aversion superior to 1.77 under CRRA hypothesis. Given that only the most risk averse agents will suscribe to an insurance and that 52% of our sample show a risk aversion superior to 1.16 we decided to test a range of values between 1 (the approximative median value) and 3 for the CRRA.

---

[9] For instance a respondent that shows switching points indicating a risk aversion parameter superior to 1.7681 and inferior or equal to .3512 to is dropped.

The parameters of the CARA[10] objective function are set in accordance: $\psi = \rho/W$, with W the average wealth (average cotton income plus initial wealth). Concerning the parameter of MASD objective function, i.e. the weight of the income semi-standard deviation relatively to the average income, we considered a set of parameter $\phi = [.25, .5, 1]$.

4.2 Basis risk and certain equivalent income

Let us suppose that the potential yield ($\bar{Y}$) depends on the (covariant or at least with spatial correlation) meteorological index (I) following a function ϕ:

$$\bar{Y}_t = \Phi(I_t) \tag{7}$$

The individual yield is composed of an idiosyncratic exogenous shock ($\epsilon_{i,t}$) and an individual fixed effect (u_i, that can alternatively be interpreted as the plot fertility as weel as the farmer's effort or experience):

$$y_{i,t} = \bar{Y}_t + \epsilon_{i,t} + u_i \tag{8}$$

The individual cotton profit of year t depends on the cotton price P_t, the quantity of inputs (F) and their price (P_t^F):

$$\Pi_{i,t} = (\phi(I_t) + \epsilon_{i,t} + u_i) \times P_t - F \times P_t^F \tag{9}$$

The individual farm income of year t depends on the non-cotton income (W_0):

$$R_{it} = W_0 + \Pi_{it} \tag{10}$$

Under such a function shape hypothesis, basis risk arises either from idiosynchratic and price shocks, from the modelisation of Φ (for instance by considering a linear relationship between the index and yield we called the model basis risk in the Chap. 3) or from the heterogeneity among individuals in terms of average yields and input use (studied in Chap. 4). We can consider that a differentiation of insurance contracts could be used to discriminate among heterogeneous farmers. Offering different premium levels corresponding to different hedging rates indeed could make contractors reveal their intended level of input use and their average yield level. As we only have observed cotton profit at the Sector level, the idiosyncratic shock cannot be assessed. However, in spite of the role of intra-village distribution in insurance calibration (Leblois et al., 2011) intra-village idiosyncratic shocks are often considered to be more easy to overcome at the village level, by private transfers through social networks (Fafchamps and Gubert, 2007). The hypothesis of income smoothing among communities and effectiveness of intra-village redistribution could be discussed, but it is not the purpose of this paper that does not have the appropriate data to address such question.

---

[10] Cf. section 3.2.2 above.

The remaining basis risk is thus the difference between the average yield at the Sector level, and village average yield, we will call it spatial basis risk thereafter. This is resulting from two potential sources. First, spatial variability of the index, i.e. the difference between the level of the index, observed at the Sector level and its realisation in each village. Second, it also results from exogenous shocks occurring at the meso or macro level, i.e. covariant exogenous shocks such as locust invasions etc.

There is not much theoretical work on the definition of basis risk in the context of index insurance calibration since Miranda (1991). The Pearson correlation coefficient between weather and yield time series is the only measure used for evaluating the basis risk since that time (see for instance Carter, 2007 and Smith and Myles, 2009). Such measure seems imperfect to us, because it does not depend on the contract shape and the utility function which will determine the capacity of insurance to improve resources allocation. We propose a tractable definition of basis risk, based on the computation of a perfect index that is the observation of the actual cotton profit at the same level for which both yield data and meteorological indices are available.

We thus consider the basis risk (BR) as the difference in percentage of utility gain obtained by smoothing income through time and space lowering the occurrence of bad cotton income through vegetation or weather index insurance (WII) as compared to an area-yield insurance (AYI) with the same contract type. We consider an insurance contract based on yield observed at the Sector level. The contract has the exact same shape[11] and the same hypothesis[12] than the WII contracts, except from the index, that is the observed outcome. We will call it AYI thereafter, considering this is the best contract possible under those hypothesis. AYI probably shows higher transaction costs than WII because of the need to asses the yield level and prevent moral hazard, however, the same loading factor and transaction costs are considered for AYI and WII to ease the comparison beteween both type of insurance.

$$BR = 1 - \frac{CEI(\tilde{\Pi}_{WII})}{CEI(\tilde{\Pi}_{AYI})} \tag{11}$$

The certain equivalent is the expected utility, average utility of all situations(years and Sector specific situations expressed in CFA francs), to which we apply the inverse of the utility function $U^{-1}(EU(\tilde{Y})$.

4.2.1 Whole cotton area

We only show the results for the period 1991-2004 in Table 5, excluding strongly unbalanced panel data before 1991 and the period 2005-2010 characterized by a collapse of the Cameroonian cotton sector with a strong decrease in yield. This latter decrease is probably due to low input use, that could have been triggered by high input prices, in

---

[11] A stepwise linear indemnification function.

[12] The premium equals the sum of payouts plus 10% of loading factor and a transaction cost.

spite of the input credit and significant subsidization. In the context of high input prices, Sodecoton's inputs misappropriation, for instance to the benefit of food crops, such as maize, is also known to happen very often.

Inter-annual variations in Sodecoton purchasing price and input costs contribute to the variations of cotton profit throughout the period. However we are not interested in computing such variations since the inter-annual variations of input and cotton prices are taken into account in crop choice as well as acreage and input use decisions. We thus value cotton and inputs at their average level over the period considered[13]. Figure 10 in the Appendix shows that such modification does not modify the shape of the distribution of profits at the Sector level. Alternatively, intra-seasonal prices variations matters, at least those occurring during the crop cycle. We address the issues related to intra-seasonal price variations in section 4.3.

Table 4: Index description.

Index name	description
CR_{obs} after sowing	Cumulative rainfall from the observed sowing date to the last rainfall
BCR_{obs} after sowing	Cumulative rainfall, capped to 30 mm per day, from the observed sowing date to the last rainfall
Length_{obs} after sowing	Length of the growing cycle, from the observed sowing date to the last rainfall
Sowing date_{obs}	Observed sowing date, in days from the first of January

In Table 4, we briefly recall the definition of each index. The first line of Table 5 shows the maximum absolute gain in percent of CEI that a stepwise insurance policy contract could bring. The rest of the table shows the gains of other indices as a share of this maximum gain, corresponding to (1-BR). The index called "Sowing date_{obs}" is the observed sowing date, in days from the first of January. In that case, as opposed to rainfall and season length indices, insurance covers against high values of the index. We display in bold insurance contract simulation that reach at least 25%.

Table 5: CEI gain of index insurances relative to AYI absolute gain from 1991 to 2004.

	CRRA			CARA			MASD		
	$\rho = 1$	$\rho = 2$	$\rho = 3$	$\psi = 1/W$	$\psi = 2/W$	$\psi = 3/W$	$\phi = .25$	$\phi = .5$	$\phi = 1$
AYI CEI **absolute** gain	.19%	.92%	1.81%	.40%	1.16%	1.88%	1.42%	3.91%	10.11%
CEI gains relative to AYI									
CR_{obs} after sowing	N.A.	3.20%	4.22%	3.29%	4.94%	7.58%	**28.22%**	**34.03%**	**36.37%**
BCR_{obs} after sowing	N.A.	3.20%	5.97%	3.29%	6.94%	10.19%	**32.45%**	**32.57%**	**34.11%**
Length_{obs} after sowing	**26.25%**	**33.66%**	**37.25%**	**32.04%**	**36.79%**	**39.95%**	**45.63%**	**47.51%**	**48.57%**
Sowing date_{obs}	**34.98%**	**50.69%**	**52.46%**	**46.43%**	**49.81%**	**52.49%**	**59.65%**	**58.57%**	**58.67%**

The first result is that the ranking among different indices performance is not modified when considering different utility functions. The MASD objective function always shows higher indemnification rate and CEI gains. It is due to the linearity of the objective

---

[13] In addition, spurious correlation was found between fertiliser price and temperatures levels after 2000; and over the whole period between cotton price and NDVI (probably corresponding to a well known phenomenon, i.e. the greening of the Sahelian zone).

function that leds to a reduced cost of basis risk. Concave utility functions (CRRA and CARA) indeed weight more low income situations, which see their income level lowered by the premium payment in the case of type one basis risk (cf. Chap. 3) i.e. when there is no payout.

Second, we observe a very high basis risk level that is always superior to almost 50% for meteorological indices. The best performing index is the length of the cotton growing season. This result is coherent with the existing literature: Sultan et al. (2010) and Marteau et al. (2011) show that the length of the rainy season, and more particularly its onset, is a major determinant of yield in the region. It is mostly explained by the fact that the cotton bolls number and size are proportional to the tree growth and development, which itself, is proportional to the length of the growing cycle. We tested various different indices[14], which all performed very poorly according to the three utility functions, most of them were indeed leading to gains that were less than 10% of the benchmark AYI gains in certain equivalent income (corresponding to a basis risk over 90%).

Third, there is a very high subzidation rate across different regions: the driest is subsidized, while the most humid is taxed, cf. Table 6 for MASD in-sample optimization with $\phi = 1$. Figure 11 in the Appendix, illustrate the inequal geographic distribution of indemnities, when calibrating insurance on the whole cotton zone. It cannot be addressed by simply standardizing meteorological index times series for two main reasons. The first is that we try to find a relation between a meteorological variable and cotton yield, which is based on a biophysical ground. Standardizing time series would thus lead to loose such relationship. Moreover as shown in Figure 9 in the Appendix, some meteorological indices show fat tails, especially on the left-hand side of the distribution, subsidization would thus not disapear with standardization.

Table 6: Net subvention rate (in percentage of the sum of preiums paid) of MASD index-based insurances across the 5 rainfall zones (RZ), for ϕ=1.

	RZ 1	**RZ 2**	**RZ 3**	**RZ 4**	**RZ 5**
CR_{obs} after sowing	4.39%	34.21%	24.05%	-60.97%	-62.57%
BCR_{obs} after sowing	-22.93%	54.15%	37.39%	-49.57%	-83.88%
Length_{obs} after sowing	41.16%	135.27%	-86.02%	-38.43%	-40.94%
Sowing date_{obs}	108.98%	139.31%	-86.20%	-59.49%	-80.57%

---

[14] From the simplest to the most complicated: annual cumulative rainfall, the cumulative rainfall over the rainy season (onset and offset set according to Sivakumar, 1988 criterion) and the simulated growing phases (GDD accumulation and cultivars characteristics), the same indices with daily rainfall bounded to 30 mm, the length of the rainy season and the length of the cotton growing season, sum and maximum bi-monthly NDVI values over the rainy season and the NDVI values over October (the end of the season), the cumulative rainfall after cotton plant emergence and the observed duration of the growing season after emergence in days...

4.2.2 Rainfall zoning

In Mali, the definition of different zones across the Malian cotton sector was needed in order to insure yields (De Bock et al., 2010). Pooling yields across heterogeneous Sectors in terms of average yields indeed leads to a subsidisation of Sectors characterized by low yields. Moreover, considering different areas associated with heterogeneous climate would also lead to subsidise drier areas in the context of an drought index-based insurance framework.

Table 7: In-sample and out-of-sample* estimated CEI gain of index insurances relative to AYI absolute gain, among different rainfall zones, from 1991 to 2004.

	CRRA		CARA		MASD	
	$\rho = 2$	$\rho = 3$	$\psi = 2/W$	$\psi = 3/W$	$\phi = .5$	$\phi = 1$
First rainfall zone						
AYI CEI **absolute** gain	1.30%	2.40%	.57%	1.10%	3.22%	8.61%
CR_{obs} after sowing	.00%	1.34%	.00%	.00%	14.73%	19.52%
	-.31%	*-.52%*	*-.09%*	*-.26%*	*-1.69%*	*-3.77%*
BCR_{obs} after sowing	7.36%	13.75%	N.A.	7.03%	19.99%	20.57%
	-18.76%	*-28.66%*	*.00%*	*-21.59%*	*-63.92%*	*-43.64%*
$Length_{obs}$ after sowing	24.47%	**34.76%**	19.66%	**30.32%**	**43.40%**	**45.15%**
	37.10%	*24.72%*	*-23.25%*	*1.61%*	***34.75%***	*12.37%*
Sowing $date_{obs}$	**37.58%**	**45.64%**	**33.89%**	**42.29%**	**39.82%**	**44.98%**
	97.74%	***91.68%***	***32.68%***	***43.58%***	***35.65%***	***63.91%***
Second rainfall zone						
AYI CEI **absolute** gain	.63%	1.43%	.17%	.44%	4.84%	12.39%
CR_{obs} after sowing	N.A.	8.64%	.00%	8.02%	6.05%	8.37%
	.19%	*.67%*	*.08%*	*.27%*	*-.81%*	*.78%*
BCR_{obs} after sowing	N.A.	9.89%	.00%	9.85%	11.53%	13.77%
	-33.13%	*9.28%*	*-115.47%*	*-14.66%*	*-16.03%*	*-25.08%*
$Length_{obs}$ after sowing	20.22%	24.85%	18.27%	**25.36%**	**39.99%**	**43.64%**
	39.96%	***49.90%***	*9.20%*	*9.08%*	*.25%*	*8.33%*
Sowing $date_{obs}$	**44.86%**	**54.61%**	**39.23%**	**55.52%**	**55.78%**	**60.82%**
	48.72%	***69.06%***	*14.52%*	*-56.34%*	*-12.35%*	*-2.49%*
Third rainfall zone						
AYI CEI **absolute** gain	.99%	2.06%	.22%	.55%	1.31%	4.22%
CR_{obs} after sowing	4.81%	4.85%	5.32%	5.33%	9.41%	9.42%
	.00%	*.00%*	*.00%*	*-.03%*	*.00%*	*.62%*
BCR_{obs} after sowing	4.81%	4.85%	5.32%	5.33%	10.62%	10.83%
	.00%	*.00%*	*N.A.*	*.00%*	*-72.74%*	*-42.67%*
$Length_{obs}$ after sowing	.00%	.89%	.00%	1.17%	2.63%	3.67%
	-178.99%	*-147.85%*	*-223.85%*	*-117.81%*	*-68.75%*	*-38.18%*
Sowing $date_{obs}$	.00%	.00%	.00%	.00%	1.26%	1.46%
	-416.22%	*-158.67%*	*-357.76%*	*-158.65%*	*-94.21%*	*-30.96%*
Fourth rainfall zone						
AYI CEI **absolute** gain	.95%	1.96%	.49%	.98%	2.85%	7.24%
CR_{obs} after sowing	.00%	1.30%	.00%	2.03%	4.20%	6.28%
	-.06%	*-.01%*	*-.03%*	*.00%*	*-.29%*	*-.35%*
BCR_{obs} after sowing	.00%	1.30%	.00%	2.03%	4.20%	6.28%
	-8.89%	*-3.62%*	*-10.74%*	*-5.46%*	*-10.08%*	*-4.30%*
$Length_{obs}$ after sowing	.00%	.00%	.00%	.00%	6.52%	8.70%
	.00%	*.00%*	*.00%*	*.00%*	*-8.02%*	*-1.93%*
Sowing $date_{obs}$	.00%	.00%	.00%	.00%	.00%	.00%
	.00%	.00%	.00%	.00%	*-11.60%*	*-8.39%*
Fifth rainfall zone sample						
AYI CEI **absolute** gain	1.49%	2.35%	.19%	.50%	1.09%	2.86%
CR_{obs} after sowing	24.15%	27.79%	20.92%	**25.12%**	**40.95%**	**41.53%**
	-.10%	*-.37%*	*-.03%*	*-.16%*	.64%	1.73%
BCR_{obs} after sowing	**47.41%**	**44.69%**	**46.01%**	**43.39%**	**51.75%**	**50.13%**
	-108.54%	*-23.07%*	*-83.17%*	*-41.19%*	***29.86%***	***47.22%***
$Length_{obs}$ after sowing	**46.60%**	**44.71%**	**45.03%**	**44.03%**	**60.44%**	**61.67%**
	-25.54%	***48.40%***	***28.24%***	***43.22%***	*4.31%*	***28.57%***
Sowing $date_{obs}$	**49.91%**	**46.82%**	**48.45%**	**45.75%**	**61.22%**	**60.21%**
	-10.80%	***78.99%***	***92.74%***	***68.33%***	***86.27%***	***102.49%***

* Leave-one-out estimations are displayed in italic

Table 7 displays, for each index, the in-sample and out-of-sample (in italic) CEI gains. We only considered two different levels of risk aversion, we chose both highests levels since only the most risk averse agents will insure (Gollier, 2004). The in-sample gains are the gain of an insurance contract calibrated and tested on the same data. This estimation thus may suffer from overfitting, which could lead to overestimate insurance gain (Leblois et al., 2012, cf. Chap. 4). On the other, for out-of-sample estimates, we calibrated, for each Sector, the insurance contract parameters on the other Sector of the same rainfall zone. Insurer profits (losses) that are superior (inferior) to the 10% charging rate are equally redistributed to each grower. This artificially keeps the insurer out-of-sample gain equal to the in-sample case and thus allows comparison with in-sample calibration estimates. We show more indices in-sample results as a percentage of each rainfall zone AYI performance in Table 11 in the Appendix.

Looking at optimizations among different rainfall zones lead to a different picture. First, for some rainfall zones, no index can be used to pool risks, that is the case of the third and the fourth rainfall zones. Both zones are quite specific in terms of agro-meteorological conditions. The Mandara mountains, present in the West of the third rainfall zone, are known to stop clouds, explaining such specificity and a relatively high annual cumulative rainfall, with very specific features. The fourth rainfall zone is corresponding to the Benoue watershed. The Benoue is the larger river of the region, contributing to more than the half the flow of the Niger river. Moreover, the fifth rainfall zone, i.e. the zone with the highest cumulative rainfall (cf. Figure 6), would mainly benefit from an index insurance based on the length of the growing cycle.

As found in the agronomic literature (Sultan, 2010 and Blanc, 2008), the length of the growing season is the index that shows higher performance in-sample. It is the only index that almost systematically leads to positive out-of-sample CEI gain estimations. However as shown in the Table 11, simulation of the sowing date using daily rainfall does not seem to be enough accurate to pool risk significantly. Once more, this result can be interpretated as an evidence of the existence of institutional constraints determinant for explaining late sowing.

Insuring against a late sowing is the most effective contract to reduce the basis risk. However, trying to simulate that observed date does not help[15]. Such result underline either the difficulty to simulate the start of the growing season or the existence of institutional delays. Delays in seed and input delivering, as mentioned by Kaminsky et al. (2011), indeed could explain some late sowing and thus the inconsistence of indices that are only based on daily rainfall observations and not on the observed sowing date.

Using the actual sowing date in an insurance contract is usually difficult because it cannot be observed costlessly by the insurer. However, in the case of cotton in French speaking West Africa, cotton production mainly relies on interlinking input-credit schemes taking place before sowing and obliging the cotton company to follow production in each production group. As mentioned by De Bock et al. (2010), cotton parastatals (i.e. Mali in their case and Cameroon in ours) already gather information about production, yield,

---

[15] There is a difference between observed and simulated cropping cycles that could be partly explained by a measure approximation of 10 days in the observed sowing date.

input use and costs and the sowing date in each region. It would thus be available at no cost to the department of production at the Sodecoton Under those circumstances observing sowing date, making it transparent and free of any distortion and including it in an insurance contract would not be so costly.

There are also potential moral hazard issues when insuring against a lately declared sowing date. However, in our case, the sowing date is aggregated at the Sector level (about 55 GP each representing about 4 000 producers, i.e. about 200 per GP). This means that a producer, and even a coordination of producer within a GP, is not able to influence the average sowing date at the Sector level by declaring a false date.

It is interesting to observe that the theoretical result of Clark (2011) seem to be realised. As found in Leblois et al. (2011, Chap. 4), a high risk aversion lead to higher the impact of basis risk on the expected utility. It means that an agent who show very high risk aversion could be reluctant to buy insurance if it shows significant basis risk.

4.3 Implicit intra-seasonal price insurance

As mentionned earlier (in section 2.1.1), Sodecoton's purchasing price does not vary as much as the international cotton price does. The cotton company is thus offering an implicit price insurance, covering intra- price insurance.

Our argument is the following: as Sodecoton announces harvest price at sowing, the firm insures growers against international intra-seasonal price variations. Furthermore, looking at the variation of Sectoral yields and intra-seasonal international cotton price variations, the latter seem to vary two times more than the first one when considering the harvest before the 1994 devaluation and the year 2010 which see a peak of cotton price (coefficient of variation of .28 for yield vs. .42 for intra-seasonal international cotton price) and at least of the same order without both those very specific years (coefficient of variation of .28 for yield vs. .20 for intra-seasonal international cotton price). However, both major shocks are positive shocks and thus do not radically modify the following analysis in terms of downside risk.

Sodecoton possibly offers such implicit price insurance at a cost, it is however very difficult to compute such cost. We will thus consider it is a free insurance mechanism, this does not affect the scope of the argument saying that the level of the price risk relatively to other risks.

Contrarily to inter-seasonal price variations that can be integrated in and compensated by cultivation and input decisions at sowing, intra-seasonal price variations cannot. We computed the relative variation between the average price during a 4 months period before sowing and compared it to the 4 month period after harvest[16]. It allows us to simulate the

---

[16] Figure 10 in the Appendix shows the observed distribution of profit of one hectare of cotton, the distribution without any inter-seasonal cotton and input price variations (black) and the distribution with intra-seasonal price variations (red). The figure shows that the inclusion of intra-seasonal price variations has a much larger impact on income risk than inter-seasonal observed price variations.

Table 8: CEI gain of intra-seasonal price and yield stabilisation (in-sample parameter calibration) in each rainfall zones (RZ) and in the whole cotton zone (CZ)

	RZ1	RZ2	RZ3	RZ4	RZ5	**CZ**
CEI gain of intra-seasonal price stab. (MASD, ϕ=.5)	3.07%	0.19%	3.49%	4.53%	4.78%	2.49%
CEI gain of intra-seasonal price stab. (CARA, ψ=2/W)	5.41%	4.96%	7.23%	8.84%	6.66%	6.72%
CEI gain of intra-seasonal price stab. (CRRA, ρ=2)	10.28%	11.33%	12.85%	17.85%	11.84%	12.98%
CEI gain of yield stab. (MASD, ϕ=.5)	2.81%	1.48%	3.26%	1.61%	3.21%	0.80%
CEI gain of yield stab. (CARA, ψ=2/W)	1.49%	1.07%	1.00%	1.77%	.40%	1.06%
CEI gain of yield stab. (CRRA, ρ=2)	3.09%	2.88%	1.91%	3.75%	.74%	2.30%

profit variations resulting from intra-seasonal price variations and to compute the gain in term of CEI of the implicit insurance offered by the cotton company. Table 8 shows the gain due to the stabilization of intra-seasonal cotton price variations as compared to the gain of a stabilization of Sectoral yield levels (fixed to the average Sectoral yield) with the observed yield distribution in each rainfall zone. The last column of Table 8 shows the CEI gain brought by the stabilization of intra-seasonal cotton international price level during the 1991-2007 period.

As a conclusion, we can say that the complete stabilization of yield bring a gain in CEI that is lower than the implicit insurance already offered by the cotton company.

5 Conclusion

The main conclusion we can draw from such results is that one should be cautious when designing and testing ex ante insurance contracts, this for two reasons. First, we show that considering a large area, with potentially different agro-ecological zones, leads, in our case, to significant cross subsidisation. It underlines the need for a precise calibration fitting local climate characteristics, even for a unique crop and in a bounded area. Cutting the cotton growing zone into smaller units, of about 1 decimal degree according to annual rainfall levels, shows that the southern part of the zone will benefit much less from such an insurance scheme. We argue that calibrating a contract that will be worth implementing is not trivial and seem to need precise agrometeorological data with a significant density of observations (depending on the spatial and inter-annual variability of the climate), at least for the Sudano-sahelian zone. This result is able to explain the very low observed take-up rates found when index based insurance where offered to farmers (i.e. Cole et al., 2012). As already mentioned in Leblois et al (2011) and Norton et al. (2012), spatial basis risk is significant and in-sample calibration thus tend to overestimate insurance gains. In the light of the out-of-sample results, the basis risk seem to have a significant impact on certain equivalent income, even when calibrating the contract parameters in order to maximise the growers expected utility.

We also show that offering rainfall index-based insurance for cotton growing in Cameroon is only able to smooth yield if the observed sowing date is available. In accordance with the agronomic literature, we found the length of the growing cycle, that determines the growing potential of the cotton tree, to be the best performing index for cotton. Moreover, insuring against a late sowing seems efficient. It however poses some moral hazard issues that probably could be overcome by the design of sowing date monitoring by the cotton companies. The revelation of sowing dates at low costs is indeed possible in many Western and Central Africa countries, were the cotton company still plays a large role in cotton cultivation campaigns.

The basis risk, as defined by the relative performance of index-based insurance to an area-yield insurance, is generally high. However, one should consider the costs of yield (or alternatively damage) observations and moral hazard issues to make a trade off between both options. In the case of cotton in a sector managed by a parastatal, such as in Cameroon where the observation of yield is already implemented at the Sector level, the gain of index-based insurance has to be compared with those latter costs.

Lastly, we found that the gain from index-based insurances was lower that the one from the implicit insurance, against intra-seasonal variations of cotton international price, offered by the national company by annoucing the purchasing price before sowing.

Acknowledgements: We thank Marthe Tsogo Bella-Medjo and Adoum Yaouba for gathering and kindly providing some of the data; Oumarou Palai, Michel Crétenet and Dominique Dessauw for their very helpful comments, Paul Asfom, Henri Clavier and many other Sodecoton executives for their trust and Denis P. Folefack, Jean Enam, Bernard Nylong, Souaibou B. Hamadou and Abdoul Kadiri for valuable assistance during the field work. All remaining erros are ours.

References

Anyamba, A., and C. Tucker (2012): *Historical Perspectives on AVHRR NDVI and Vegetation Drought Monitoring.* In: Remote Sensing of Drought: Innovative Monitoring Approaches; Brian, D . Wardlow, Martha C . Anderson, and James P . Verdin.

Araujo-Bonjean, C., J.-L. Combes, and P. Plane (2003): “Preserving vertical Co-ordination in the West African Cotton Sector,” Discussion paper, CERDI.

Baron, C., B. Sultan, B. Maud, B. Sarr, S. Traore, T. Lebel, S. Janicot, and M. Dingkuhn (2005): “From GCM grid cell to agricultural plot: scale issues affecting modelling of climate impact,” *Phil. Trans. R. Soc.*, 360, 2095–2108.

Bella-Medjo (Tsogo), M. (2009): “Analyse multi-chelle de la variabilité pluviométrique au cameroun et ses conséquences sur le rendement du coton,” Ph.D. thesis, Université Pierre et Marie Curie.

Berg, A., P. Quirion, and B. Sultan (2009): "Can weather index drought insurance benefit to Least Developed Countries' farmers? A case study on Burkina Faso," *Weather, Climate and Society*, 1, 7184.

Blanc, E., P. Quirion, and E. Strobl (2008): "The climatic determinants of cotton yields: Evidence from a plot in West Africa," *Agricultural and Forest Meteorology*, 148(6-7), 1093 – 1100.

Boko, M., I. Niang, A. Nyong, C. Vogel, A. Githeko, M. Medany, B. Osman-Elasha, R. Tabo, and P. Yanda (2007): "Africa: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)," *Climate Change 2007*, p. 433467, In: Parry et al. (2007).

Boussard, J. (2007): *La régulation des marchés agricoles internationaux: Un enjeu décisif pour le développement*, Biologie, écologie, agronomie. Harmattan.

Brambilla, I., and G. G. Porto (2011): "Market structure, outgrower contracts, and farm output. Evidence from cotton reforms in Zambia," *Oxford Economic Papers*, 63(4), 740–766.

Cai, J. (2012): "Social Networks and the Decision to Insure: Evidence from Randomized Experiments in China," Discussion paper, University of California Berkeley.

CIRAD-GRET (2002): *Mémento de l'agronome*. Ministère des affaires étrangères.

Claassen, R., and R. E. Just (2011): "Heterogeneity and Distributional Form of Farm-Level Yields," *American Journal of Agricultural Economics*, 93(1), 144–160.

Cole, S., X. Gin, J. Tobacman, P. Topalova, R. Townsend, and J. Vickrey (forthcoming): "Barriers to Household Management: Evidence from India," *American Economic Journal: Applied Economics.*

Crétenet, M. (2010): "Questions de recherche à résoudre pour une relance durable des productions en zone cotonnière," in *Séminaire Géocoton; Relance durable des productions en zone cotonnière : outils et stratégies.*

Crétenet, M., and D. Dessauw (2006): "Production de coton-graine de qualité, guide technique No.1," Discussion paper, CIRAD.

De Bock, O., M. Carter, C. Guirkinger, and R. Laajaj (2010): "Étude de faisabilité: Quels mécanismes de micro-assurance privilégier pour les producteurs de coton au Mali ?," Discussion paper, Centre de Recherche en Economie du Développement, FUNDP - Département de sciences économiques.

Delpeuch, C., and A. Leblois (Forthcoming): “Sub-Saharan African cotton policies in retrospect,” *Development Policy Review.*

Dessauw, D., and B. Hau (2008): “Cotton breeding in French-speaking Africa: Milestones and prospectss,” in *Invited paper for the Plant Breeding and Genetics research topic.*

Enam, J., D. Folefack, C. Kouebou, and M. Fok (2009): “Tottering associative process in Cameroon: Collateral damage of the cotton policy adjustment,” *Life sciences international journal*, pp. 112–122, Cotton Conference on ”Rationales and Evolution of Cotton Policies”, 2008-05-13/2008-05-17.

Fafchamps, M., and F. Gubert (2007): “The formation of risk sharing networks,” *Journal of Development Economics*, 83(2), 326–350.

Folefack, D. P., J. Kaminski, and J. Enam (2011): “Note sur le contexte historique et gestion de la filière cotonnière au Cameroun,” *WP.*

Fontaine, J. M., and A. Sindzingre (1991): “Structural Adjustment and Fertilizer Policy in Sub-Saharan Africa,” Discussion paper, OECD.

Freeland, J. T. B., B. Pettigrew, P. Thaxton, and G. L. Andrews (2006): “Chapter 13A in guide to agricultural meteorological practices,” in *Agrometeorology and cotton production.*

GAMP (2010): “Guide to Agricultural Meteorological Practices,” Discussion paper, World Meteorological Organization, Commission for Agricultural Meteorology report No.134.

Gergely, N. (2009): “The cotton sector of Cameroon,” *World Bank*, Africa Region Working Paper No.126.

Giné, X., D. Karlan, and M. Ngatia (2012): “Social networks, financial literacy and index insurance,” Discussion paper, Yale.

Giné, X., and D. Yang (2009): “Insurance, Credit, and Technology Adoption: Field Experimental Evidence from Malawi,” *Journal of Development Economics*, 89, 1–11.

Gollier, C. (2004): *The Economics of Risk and Time*, vol. 1. The MIT Press, 1 edn.

Gray, A. W., M. D. Boehlje, B. A. Gloy, and S. P. Slinsky (2004): “How U.S. Farm Programs and Crop Revenue Insurance Affect Returns to Farm Land,” *Applied Economic Perspectives and Policy*, 26(2), 238–253.

Hayes, M., and D. W.L. (1996): "Using NOAA AVHRR data to estimate maize production in the United States Corn Belt," *International Journal of Remote Sensing*, 17, 3189–3200.

Holt, C. A., and S. K. Laury (2002): "Risk Aversion and Incentive Effects," *American Economic Review*, 92, 1644–1655.

International Cotton Advisory Committee (ICAC) (2007): "Global warming and cotton production Part 1," Discussion paper.

——— (2009): "Global warming and cotton production Part 2," Discussion paper.

IPCC (2007): "Climate Change: Impacts, Adaptation and Vulnerability," *Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)*, p. 581615.

Kaminski, J., J. Enam, and D. P. Folefack (2011): "Hétérogénéité de la performance contractuelle dans une filière intégre : cas de la filière cotonnière camerounaise," *WP*.

Kenga, R., M. M'Biandoun, A. Njoya, M. Harvard, and E. Vall (2002): "Analysis of constraints to agricultural production in the Sudano-Sahelian zone of Cameroon using a diagnostic survey," in *Savanes africaines: des espaces en mutation, des acteurs face à de nouveaux défis*.

Leblois, A., and P. Quirion (forthcoming): "Agricultural Insurances Based on Meteorological Indices: Realizations, Methods and Research Challenges," *Meteorological Applications*.

Leblois, A., P. Quirion, A. Alhassane, and S. Traoré (2011): "Weather index drought insurance: an ex ante evaluation for millet growers in Niger," Discussion paper, CIRED.

Levrat, R. (2010): *Culture commerciale et développement rural l'exemple du coton au Nord-Cameroun depuis 1950*. L'Harmattan.

Lien, G., and J. Hardaker (2001): "Whole-farm planning under uncertainty: impacts of subsidy scheme and utility function on portfolio choice in Norwegian agriculture," *European Review of Agricultural Economics*, 28(1), 17–36.

Luo, Q. (2011): "Temperature thresholds and crop production: a review," *Climatic Change*, 109, 583–598, 10.1007/s10584-011-0028-6.

MAKDISSI, P., and Q. WODON (2004): "Price Liberalization and Farmer Welfare Under Risk Aversion: Cotton in Benin and Ivory Coast," Discussion paper.

Marteau, R., B. Sultan, V. Moron, A. Alhassane, C. Baron, and S. B. Traor (2011): “The onset of the rainy season and farmers sowing strategy for pearl millet cultivation in Southwest Niger,” *Agricultural and Forest Meteorology*, 151(10), 1356 – 1369.

Maselli, F., C. Conese, L. Petkov, and M. Gialabert (1993): “Environmental monitoring and crop forecasting in the Sahel trought the use of NOAA NDVI data. A case study: Niger 1986-89,” *International Journal of Remote Sensing*, 14, 3471–3487.

Mayeyenda, A., and P. Hugon (2003): “Les effets des politiques des prix dans les filières coton en Afrique zone franc: analyse empirique,” *Économie rurale*, 275(1), 66–82.

Mbetid-Bessane, E., M. Harvard, K. Djondang, D. Kadekoy-Tigague, D.-P. Folefack, D. Reoungal, and J. Wey (2009): “Adaptation des exploitations agricoles familiales en à la crise cotonnière en Afrique centrale,” in *Savanes africaines en développement: innover pour durer*, vol. 19.

McLaurin, M. K., and C. G. Turvey (2011): “Applicability of the Normalized Difference Vegetation Index in Index-Based Crop Insurance Design,” *SSRN eLibrary*.

Meroni, M., and M. Brown (2012): “Remote sensing for vegetation monitroing: potential applications for index insurance,” Ispra. JRC, ftp://mars.jrc.ec.europa.eu/index-insurance-meeting/presentations/7_meroni_brown.pdf.

Miranda, M. J. (1991): “Area-Yield Crop Insurance Reconsidered,” *American Journal of Agricultural Economics*, 73, 233–242.

Norton, M. T., C. G. Turvey, and D. E. Osgood (2012): “Quantifying Spatial Basis Risk for Weather Index Insurance,” *The Journal of Risk Finance*, 14.

Odekunle, T. O. (2004): “Rainfall and the length of the growing season in Nigeria,” *International Journal of Climatology*, 24(4), 467–479, 10.1007/s00704-005-0166-8.

Pinzon, J., M. Brown, and C. Tucker (2005): *Satellite time series correction of orbital drift artifacts using empirical mode decomposition.*

Sadou, F., A. Abdoulaye, B. Oumarou, M. Theze, and Y. Oumarou (2007): “Demarche de diffusion des SCV dans la zone cotonnière du Nord Cameroun: dispositifs, atouts, limites,” in *Séminaire régional sur l’agroécologie et les techniques innovantes dans les systèmes de production cotonniers.*

Shepard, D. (1968): “A two-dimensional interpolation function for irregularly-spaced data,” in *Proceedings of the 1968 23rd ACM national conference*, ACM ’68, pp. 517–524, New York, NY, USA. ACM.

Sivakumar, M. V. K. (1988): "Predicting rainy season potential from the onset of rains in Southern Sahelian and Sudanian climatic zones of West Africa," *Agricultural and Forest Meteorology*, 42(4), 295 – 305.

Smith, V. H., and M. A. Watts (2009): "Index Based Agricultural Insurance in Developing Countries: Feasibility, Scalability and Sustainability," Discussion paper, Monograph published electronically by the B ill and Melinda Gates Foundation.

Sultan, B., M. Bella-Medjo, A. Berg, P. Quirion, and S. Janicot (2010): "Multi-scales and multi-sites analyses of the role of rainfall in cotton yields in West Africa," *International Journal of Climatology*, 30, 58–71.

Vitale, J. D., H. Djourra, and A. Sidib (2009): "Estimating the supply response of cotton and cereal crops in smallholder production systems: recent evidence from Mali," *Agricultural Economics*, 40(5), 519–533.

Yaouba, A. (2009): "Présentation du contexte agro-écologique et socio-économique de la zone cotonnière du Cameroun," Discussion paper, Sodecoton.

A Additional indices tested

A.1 Growing phases schedule

We then, try to distinguish different growing phases of the cotton crop, indices based on that growing phases schedules will be referred as *sim gdd*. Cutting-in growing phases allows to determine a specific trigger for indemnifications in each growing phase. We do that by defining emergence, which occurs when reaching an accumulation of 15 mm of rain and 35 growing degree days (GDD)[17] after the sowing date. We then set the length of each of the 5 growing phases following emergence only according to the accumulation of GDD, as defined by the *Mémento de l'agronome* (2002), Crétenet et al. (2006) and Freeland et al. (2006). The end of each growing phases are triggered by the following thresholds of degree days accumulation after emergence: first square (400), first flower (850), first open boll (1350) and harvest (1600). The first phase begins with emergence and ends with the first square, the second ends with the first flower. The first and second phases are the vegetative phases, the third phase is the flowering phase (reproductive phase), the fourth is the opening of the bolls, the fifth is the maturation phase that ends with harvest.

The use of different cultivars, adapted to the specificity of the climate (with much shorter growing cycle in the drier areas) requires to make a distinction different seasonal schedule across time and space. For instance, recently, the IRMA D 742 and BLT-PF

---

[17] Calculated upon a base temperature of 13 °C.

cultivars were replaced in 2007 by the L 484 cultivar in the Extreme North and IRMA A 1239 by the L 457 in 2008 in the North province. We simulated dates of harvest and critical growing phases[18] using Dessauw and Hau (2002) and Levrat (2010). The beginning and end of each phase were constraint to fit each cultivar's growing cycle (Table 9 in the Appendix review the critical growing phases for each cultivar).

The total need is 1600 GDD, corresponding to about an average of 120 days in the considered producing zone, the length of the cropping season thus seem to be a limiting factor, especially in the upper zones (Figure 5) given that an average of 150 needed for regular cotton cultivars, Crétenet et al. (2006).

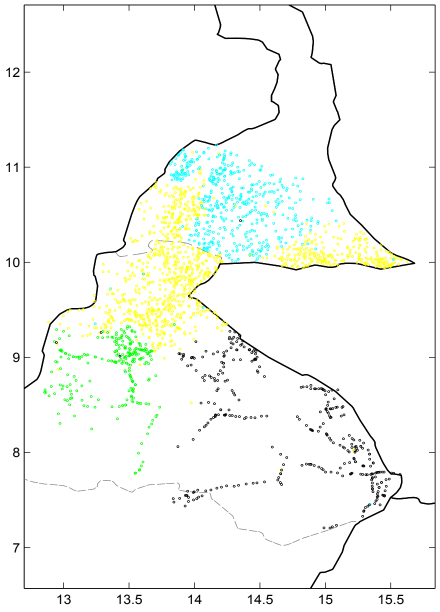

Figure 4: Spatial repartition of cultivars in 2010, dots are representing producers groups buying seeds, IRMA 1239 in black, IRMA A 1239 in green, IRMA BLT-PF in yellow and IRMA D742 in cyan.

A.2 Remote sensing indicators

According to Anyamba and Tucker (2012), MODIS derived products, such as NDVI, can not directly be used for drought monitoring or insurance since it requires huge delays in data processing, homogenization from difference satellites data source and validation from research scientists. However, they underline the existence of very similar near real-time

---

[18] See Figure 4 in the the Appendix for the spatial distribution of cultivars and Table 9 for the description of all cultivars and schedules.

Table 9: Cotton cultivars average spatial and temporal allocation

Cultivars ***(by province)***	1^{st} **flower date** (Days after emergence)	1^{st} **boll date** (Days after emergence)	**Period of use**
Allen commun	61	114	untill 1976
444-2			untill 1976
Allen 333	59	111	1959-197?
BJA 592	61	114	1965-197?
IRCO 5028	61	111	untill 1987
IRMA 1243	53	102	1987 - 1998
IRMA 1239	52	101	2000-2007
IRMA A 1239	52	101	2000-2007
L 457	52	104	2008-onwards
Extrême-Nord			
IRMA L 142-9	59	109	until 1984
IRMA 96+97	55	115	1985 - 1991
IRMA BLT	51	99	1999-2002
IRMA BLT-PF	56	116	2000 - 2006
IRMA D 742	51	95	2003-2006
IRMA L 484	51	105	2007 - onwards

Sources: Dessauw (2008) and Levrat (2010).

(less than 3 hours from observation) products, such as eMODIS from USGS EROS used for drought monitoring by FEWS.

There is also a cost in terms of transparency to use such complex vegetation index that is not directly understandable for smallholders. There is thus a trade-off to be made between delays (minimized when using near real-time products), transparency and basis risk. In a similar study in Mali (De Bock et al., 2010) vegetation index is found to be more precise than rainfall indices following a criterion of basis risk (defined as the correlation between yield and the index).

We used the bi-monthly satellite imagery (above-mentioned NDVI) during the growing season: and considered annual series from the beginning of April to the end of October. We standardized the series, for dropping topographic and soil specificities, following Hayes and Decker (1996) and Maselli et al. (1993) in the case of the Sahel. There is 2 major ways of using NDVI: one can alternatively consider the maximum value or the sum of the periodical observation of the indicator (that is already a sum of hourly or daily data) for a given period (say the GS). As an example Meroni and Brown (2012) proxied biomass production by computing an integral of remote sensing indicators (in that particular case: FAPAR) during the growing period. Alternatively considering the maximum over the period is also possible since biomass (and thus dry weight) is not growing linearly with photosynthesis activity during the cropping season, but grows more rapidly when NDVI is high. Turvey (2011) for instance considers, in the case of index insurance, that the maximum represents the best vegetal cover attained during the GS and will better proxy yields. We thus tried indices using both methods but also consider the bi-monthly observations of standardized NDVI.

B Definition of rainfall zones

Average annual cumulative rainfall varies between 600 and 1200 mm in the cotton producing area characterized by a Sudano-sahelian climate, and more precisely: Sudanian in the Southern part and Sudano-sahelian in the Northern part.

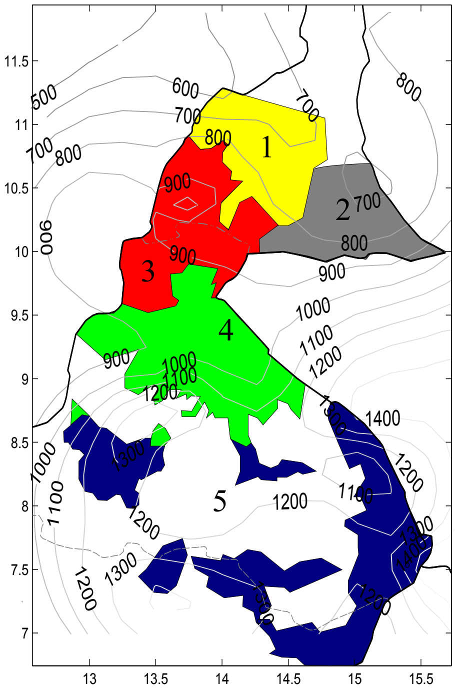

Figure 5: Zoning of cotton cultivation zone, based on meteorological (annual cumulative rainfall) classification (different areas are called North: 1, North East: 2, North West: 3, Centre: 4 and South: 5) and isohyets (in mm on the 1970-2010 period). Source: authors calculations.

We defined five zones only following rainfall levels of each Sector (referred as rainfall zones below), sorting them by average annual cumulative rainfall on the whole period and grouping them in order to get a significant sample. The geographical zoning of the cotton cultivations area is displayed in Figure 6 and the distribution of yields, annual cumulative rainfall and length of the rainy season for each zones in Figure 5.

The rainfall zones have significantly (student, probability of error lower than 1%) different average yield, cumulative rainfall and cotton growing season length. As mentioned in the section 3.1, yield seem very sensitive to the sowing date. The two northern rainfall zones are sowed (and emerge) 10 to 15 days later; such feature could explain part of the discrepancies among yields, in spite of the development of adapted cultivars for each zone by the agronomic research services.

However, in our case, optimizing insurance in each of the rainfall zones lead to largely better pooling for each of them, but standardizing[19] indices by Sector did not improved

---

[19] Considering the ratio of the deviation of each observation to the Sector average yield on its standard

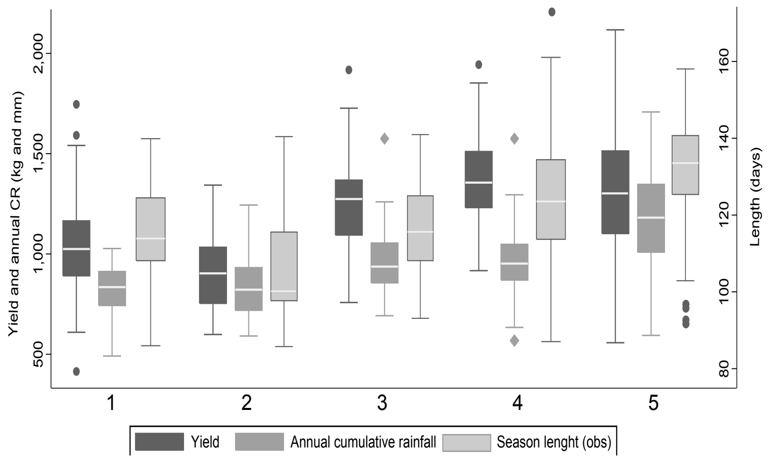

Figure 6: Boxplots of Yield, Annual rainfall and cotton growing season duration in different rainfall zones.

significantly the results.

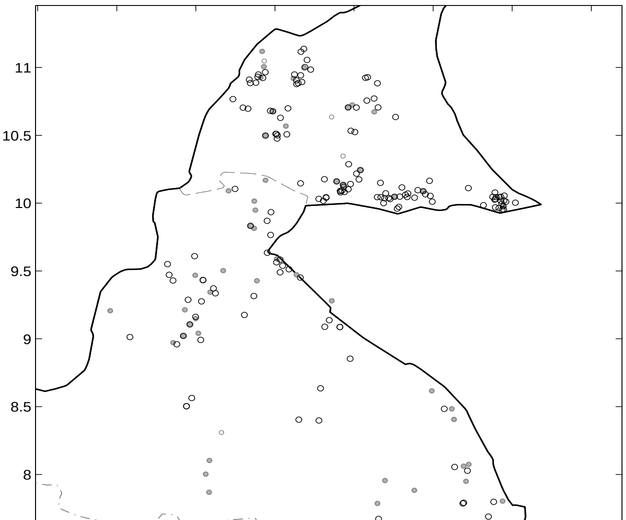

Figure 7: Sodecoton's surveys localization: light gray dots for 2003, gray circles for 2006 and black circles for 2010.

---

deviation.

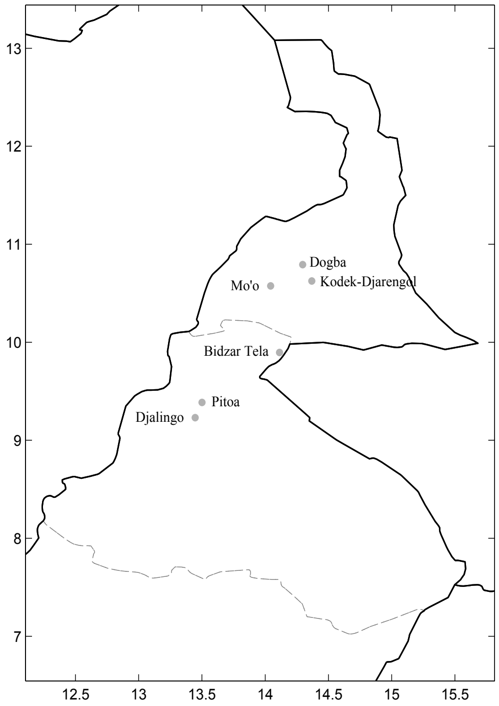

Figure 8: Villages in which lotteries were implemented.

Table 10: Risk aversion summary statistics

Variable	**Mean**	**Std. Dev.**	**Min.**	**Max.**	**N**
ρ	1.635	1.181	0	3	64
Among which:					
ρ (Dogba)	1.35	0.539	0.724	1.768	10
ρ (Mo'o)	1.796	1.302	0	3	10
ρ (Djarengol-Kodek)	1.897	1.199	0	3	11
ρ (Bidzar)	2	1.5	0	3	9
ρ (Pitoa)	0.901	0.75	0	3	12
ρ (Djalingo)	1.958	1.371	0	3	12

Source: Authors calculations.

Note: risk aversion level that are found to be superior to 2 are arbitrarily set to 3 and those found inferior or equal to zero are set to zero.

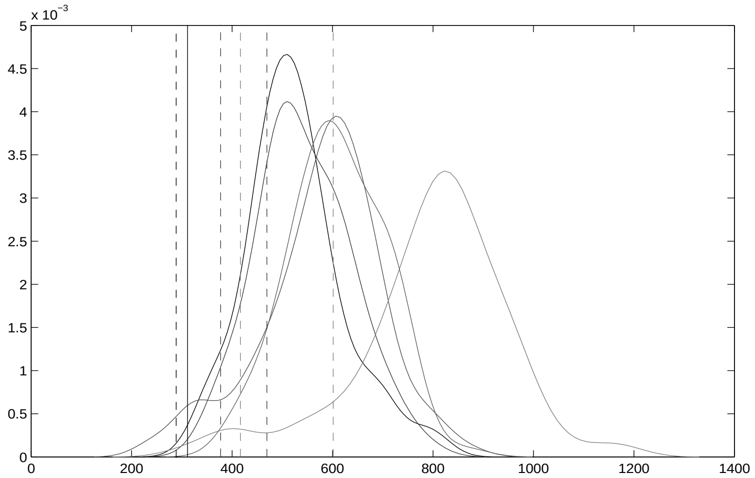

Figure 9: Distribution of length of growing season by rainfall zone, the vertical axes represent the strike levels, in black the level when calibrating on the whole sample and in grey and the levels when considering different rainfall zones.

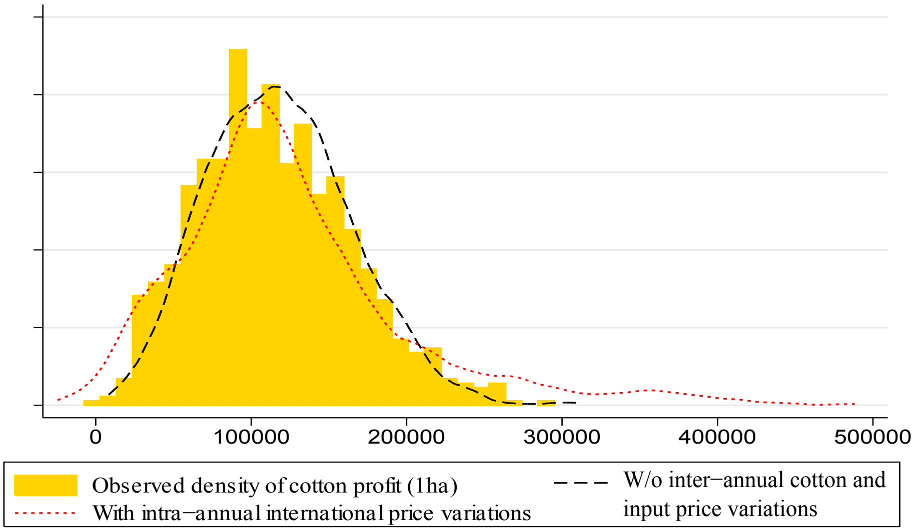

Figure 10: Distribution of cotton profit for one hectare, after reimbursement of inputs (in yellow the observed distribution, in black the kernel density of the simulated profit when considering fixed inter-annual cotton and input prices and in red the simulated distribution when adding international intra-seasonal prices variations).

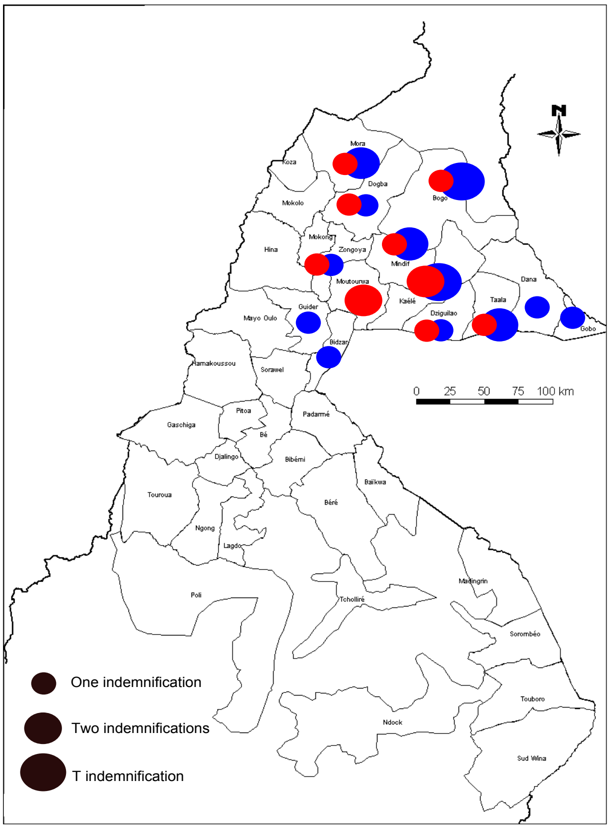

Figure 11: Indemnifications of two WII contracts: % of area sown at the 30 of June (red) and BCR_{obs} (blue); both optimized with a CRRA and $\rho = 2$ between 1991 and 2004).

Table 11: Share of the maximum risk premium reduction among different indices and different rainfall zones (1991-2004).

	CRRA			CARA			MASD		
	$\rho = 1$	$\rho = 2$	$\rho = 3$	$\psi = 1/W$	$\psi = 2/W$	$\psi = 3/W$	$\phi = .25$	$\phi = .5$	$\phi = 1$
First rainfall zone									
Annual cumulative rainfall (CR)	.00%	.00%	1.88%	.00%	.00%	.00%	13.26%	12.99%	12.73%
CR$_{sim}$	5.94%	5.74%	5.31%	N.A.	6.23%	5.80%	24.85%	21.09%	19.57%
BCR$_{sim}$	5.94%	5.74%	5.31%	N.A.	6.23%	5.80%	24.83%	21.06%	19.61%
CR$_{simgdd}$	5.94%	5.81%	5.74%	N.A.	6.56%	6.58%	27.17%	24.02%	22.66%
BCR$_{simgdd}$	5.94%	5.89%	5.89%	N.A.	6.69%	6.74%	27.71%	24.61%	23.26%
CR$_{obs}$ after sowing	.00%	.00%	1.34%	.00%	.00%	.00%	5.86%	14.73%	19.52%
BCR$_{obs}$ after sowing	.00%	7.36%	13.75%	.00%	N.A.	7.03%	18.40%	19.99%	20.57%
Length$_{sim}$	.00%	.00%	.00%	.00%	.00%	.00%	7.79%	8.42%	8.51%
Length$_{simgdd}$	.00%	.00%	1.05%	.00%	.00%	N.A.	10.76%	11.16%	15.42%
Length$_{obs}$ after sowing	6.52%	24.47%	34.76%	N.A.	19.66%	30.32%	39.83%	43.40%	45.15%
Standardized NDVI (Oct. 1-15)	.00%	.00%	.00%	.00%	.00%	.00%	-2.68%	1.64%	10.36%
Sowing date$_{obs}$	.00%	37.58%	45.64%	.00%	33.89%	42.29%	25.92%	39.82%	44.98%
AYI	.46%	1.90%	3.66%	.17%	.77%	1.45%	1.97%	5.35%	13.78%
Second rainfall zone									
Annual cumulative rainfall (CR)	.00%	.00%	.00%	N.A.	.00%	.00%	15.72%	22.49%	26.69%
mm. per day in ph. 2	N.A.	7.93%	8.22%	N.A.	8.53%	8.84%	40.94%	40.17%	39.40%
CR$_{sim}$	.00%	.00%	.00%	N.A.	.00%	.00%	5.20%	11.75%	16.74%
BCR$_{sim}$	.00%	4.20%	5.62%	N.A.	N.A.	5.70%	21.57%	21.41%	22.42%
CR$_{simgdd}$	.00%	.00%	.00%	N.A.	.00%	.00%	.00%	5.10%	7.44%
BCR$_{simgdd}$	.00%	.00%	.00%	N.A.	.00%	.00%	2.33%	7.29%	8.93%
Length$_{sim}$	.00%	1.76%	2.04%	N.A.	N.A.	2.25%	17.88%	22.68%	29.15%
Length$_{simgdd}$	.00%	.00%	2.98%	N.A.	.00%	.00%	26.97%	41.29%	45.78%
Length$_{obs}$ after sowing	.00%	20.22%	24.85%	N.A.	18.27%	25.36%	27.21%	39.99%	43.64%
CR$_{obs}$ after sowing	.00%	N.A.	8.64%	N.A.	.00%	8.02%	3.83%	6.05%	8.37%
BCR$_{obs}$ after sowing	.00%	N.A.	9.89%	N.A.	.00%	9.85%	6.15%	11.53%	13.77%
Standardized NDVI (Oct. 1-15)	.00%	.00%	.00%	N.A.	.00%	.00%	1.26%	3.20%	4.79%
Sowing date$_{obs}$	.00%	44.86%	54.61%	N.A.	39.23%	55.52%	34.74%	55.78%	60.82%
AYI	.05%	.62%	1.38%	.01	.17%	.42%	1.11%	3.61%	10.03%
Third rainfall zone									
Annual cumulative rainfall (CR)	.00%	.00%	.00%	.00%	.00%	.00%	.00%	.00%	.00%
CR$_{obs}$ after sowing	.00%	.00%	1.30%	.00%	.00%	2.03%	.00%	4.20%	6.28%
BCR$_{obs}$ after sowing	.00%	.00%	1.30%	.00%	.00%	2.03%	.00%	4.20%	6.28%
Length$_{simgdd}$	.00%	.00%	.00%	.00%	.00%	.00%	.00%	.00%	.00%
Length$_{obs}$ after sowing	.00%	.00%	.00%	.00%	.00%	.00%	.00%	2.13%	5.08%
Length$_{obs}$ after emergeance	.00%	.00%	.00%	.00%	.00%	.00%	1.33%	6.52%	8.70%
Standardized NDVI (Oct. 1-15)	.00%	.00%	.00%	.00%	.00%	.00%	.00%	.00%	.00%
Sowing date$_{obs}$	.00%	.00%	.00%	.00%	.00%	.00%	.00%	.00%	.00%
AYI	.16%	.94%	1.88%	.08%	.47%	.93%	1.03%	3.04%	7.94%
Fourth rainfall zone									
Annual cumulative rainfall (CR)	N.A.	8.22%	7.71%	N.A.	9.03%	8.22%	36.18%	32.41%	30.99%
mm. per day in ph. 2	16.47%	8.93%	7.43%	N.A.	9.42%	8.02%	36.31%	31.53%	29.77%
CR$_{sim}$	.00%	6.57%	6.30%	.00%	7.65%	7.22%	35.51%	32.13%	31.01%
BCR$_{sim}$	.00%	2.18%	3.20%	.00%	N.A.	4.04%	23.37%	23.68%	24.13%
CR$_{simgdd}$	.00%	6.57%	6.30%	.00%	7.65%	7.22%	35.51%	32.93%	32.00%
BCR$_{simgdd}$	N.A.	6.14%	5.65%	.00%	6.80%	6.27%	26.68%	25.59%	25.11%
CR$_{obs}$ after sowing	N.A.	24.15%	27.79%	N.A.	20.92%	25.12%	47.28%	40.95%	41.53%
CR$_{obs}$ after emergeance	57.45%	46.60%	44.71%	55.11%	45.03%	44.03%	59.17%	60.44%	61.67%
BCR$_{obs}$ after sowing	51.56%	47.41%	44.69%	48.97%	46.01%	43.39%	58.52%	51.75%	50.13%
Length$_{sim}$	31.67%	14.33%	11.85%	31.84%	14.47%	11.86%	26.84%	24.54%	23.66%
Length$_{simgdd}$	.00%	.00%	2.20%	.00%	.00%	N.A.	22.73%	22.92%	23.84%
Length$_{obs}$ after sowing	57.45%	46.60%	44.71%	55.11%	45.03%	44.03%	59.17%	60.44%	61.67%
Standardized NDVI (Oct. 1-15)	47.84%	23.82%	20.13%	46.96%	23.80%	19.92%	.84%	6.45%	22.99%
Sowing date$_{obs}$	69.48%	49.91%	46.82%	66.54%	48.45%	45.75%	66.33%	61.22%	60.21%
AYI	.29%	1.40%	2.73%	.12%	.63%	1.20%	1.31%	3.99%	10.73%
Fifth rainfall zone sample									
Annual cumulative rainfall (CR)	N.A.	4.17%	3.92%	N.A.	4.48%	4.20%	18.33%	15.54%	14.29%
CR$_{sim}$	N.A.	4.17%	3.92%	N.A.	4.48%	4.20%	17.84%	14.67%	13.32%
BCR$_{sim}$	.00%	4.17%	3.92%	N.A.	4.48%	4.20%	17.85%	14.69%	13.34%
CR$_{simgdd}$	N.A.	4.17%	3.92%	N.A.	4.48%	4.20%	17.81%	14.65%	13.30%
BCR$_{simgdd}$	N.A.	4.17%	3.92%	N.A.	4.48%	4.20%	17.81%	14.65%	13.30%
mm. per day in ph. 2	.00%	.00%	.00%	.00%	.00%	.00%	8.28%	6.62%	6.18%
Accumulation of GDD during ph. 5	28.54%	34.50%	33.51%	26.92%	33.76%	32.87%	18.33%	18.04%	19.06%
CR$_{obs}$ after sowing	N.A.	4.81%	4.85%	N.A.	5.32%	5.33%	9.31%	9.41%	9.42%
BCR$_{obs}$ after sowing	N.A.	4.81%	4.85%	N.A.	5.32%	5.33%	9.80%	10.62%	10.83%
Length$_{sim}$	.00%	2.51%	5.12%	.00%	N.A.	4.61%	10.17%	8.87%	8.25%
Length$_{simgdd}$	.00%	.00%	.00%	.00%	.00%	.00%	12.90%	10.56%	9.57%
Length$_{obs}$ after sowing	.00%	.00%	.89%	.00%	.00%	1.17%	N.A.	2.63%	3.67%
Standardized NDVI (Oct. 1-15)	.00%	.00%	.00%	.00%	.00%	.00%	2.59%	3.82%	7.50%
Sum of GS bi-bi-monthly NDVI	N.A.	9.66%	9.25%	N.A.	9.84%	9.43%	18.82%	16.06%	15.26%
Sowing date$_{obs}$	.00%	.00%	.00%	.00%	.00%	.00%	N.A.	1.26%	1.46%
AYI	.10%	.91%	1.87%	.05%	.44%	.88%	.81%	2.57%	6.72%