Agricultural insurances based on weather indices: realizations, methods and limitations

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Abstract

Low-income countries are mostly endowed with rainfed agriculture. Therefore yields mostly depend on climatic factors. Furthermore, farmers have little access to traditional crop insurance. Insurances based on meteorological indices could fill this gap if transparent, cheap and straightforward. However their implementation has been limited so far.

In this chapter, we first describe different projects that took place in developing countries using these types of insurances. We then review the underlying methodology that has been or should be used when designing and assessing the potential of such recent but numerous projects and empirical results of experimetal projects. We finally introduce future challenges to be addressed for supplying index insurances to farmers.

Contents

1 Index-based insurance in developing countries: a review

In traditional crop insurance, the insurer pays an indemnity to the farmer when crops are damaged, typically by drought, hail or frost (the so-called "multirisk" crop insurance). In that case, information asymmetry between farmers and the insurer about the actual effort put into production creates moral hasard issues. Moreover, information asymmetry about the veracity of the claims makes the insurer resort to a costly and transaction costs. As a consequence, such insurances exist only where they are largely subsidized by the government. We can quote as examples PROPAGRO in Brazil, INS in Costa Rica, CCIS in India, ANAGSA and the FONDEN program in Mexico, PCIC in the Philippines, Agroseguro in Spain, and FCIC in the USA, for which every respective government pays for more than half of the premiums (Miranda and Glauber, 1997, Molini et al., 2010, Mahul and Stutley, 2010, Fuchs and Wolff 2011b). Unfortunately, developing countries governments' do not have the financial resources to finance these subsidies at a large scale.

Weather index insurances (WII) may constitute an interesting alternative, especially for these countries. The difference with traditional crop insurance is that indemnification is not triggered by damage to the crop, but by the level of a meteorological index, which is itself assumed to be correlated to crop yield. WIIs are analogous to weather derivatives, which appeared in the 1990s in the energy sector. Those latter financial products reduce the impact of climatic shocks on firms whose margins widely depend on climate, such as energy suppliers.

The main advantage of WIIs over traditional insurance is that there is no need for damage assessment. Thanks to an easily observable index the principal (the insurer) does not have to check the agent's (the insured farmer) statement (Quiggin et al., 1993). Moreover, a transparent and fast transmission of information allows quick payouts.

As a consequence of their simplicity a so-called basis risk possibly lies in such policies, i.e. the fact that the correlation between crop yields and the meteorological index cannot be perfect. Indeed the relationship between weather and yield is complex and depends on field-specific features such as the type of soil or the farmer practices. Moreover, many hazards independent of the weather do impact yields. Finally, a high spatial variability of the weather (section 2.5.2) also contributes to the basis risk, since it would be too costly to install a rain gauge, let alone a complete meteorological station, in every field. We will explain basis risk in greater detail in section 1.3.3. To minimize the basis risk, the chosen meteorological index must be a good predictor of yields, and especially of bad yields. One should finally balance advantages and impediments of WII compared to traditional insurances, that is what we will try to do in this review.

A few articles have investigated the impact of crop insurance based on weather index in developing or transition countries (Berg et al., 2009 in Burkina Faso, Breustedt et al., 2008 in Ukraine, Chantarat et al., 2008 in Kenya, Molini et al., 2010 and Muamba and Ulimwengu (2010) in Ghana, De Bock et al., 2010 in Mali and Zant, 2008 in India). Ex-post studies are developing very fast in recent years due to the recent development of such products (Cai et al., 2009 in China; Fuchs and Wolff 2011a and 2011b in Mexico; Hill and Viceisza, 2009 in Ethiopia; Karlan et al., 2012 in Ghana; Giné and Yang, 2009 in Malawi and Cole et al. 2011 and Giné et al., 2008 in India).

However mostly due to data scarcity, products that were launched were rarely based on a baseline study using long run weather and yield data. Ex-post studies mostly concentrate on demand (take up rates) and there is no empirical evidence of the actual gain interest of such products for farmers in developing countries. The occurrence of indemnification being low, running a randomized controlled trial (RCT, Duflo, 2004) on such program is quite expensive and takes a lot of time. Fuchs and Wolff (2011b) is an exception, they studied the impact of the mexican programme in a natural experiment study using variations in insurance supply during the launching phase (2003-2008). They find a positive impact on yield (7%) and on income (8%), with income gain concentrated in medium-income counties. The authors however found the program cost-ineficient as a whole, especially due to high premium, representing twice the expected indemnity for the period 1990-2008, entirely subsidized by the mexican government.

1.1 Main experiments in developing countries to date

Most WIIs projects implemented in developing countries aim at insuring individual farmers. Although distinction between low income and middle income countries could be questioned, we will bound our analysis to developing countries, since we mostly care about replicability in West Africa. Malawi and India were the low-income countries with the biggest experience of index micro-insurance at the time this survey was written (in 2009[1]) and thus represent a large part of this work. We also draw attention about a rather different type of WII that was implemented in Ethiopia on a 'macro' scale.

1.1.1 India

India introduced traditional crop insurance in 1965 and WIIs in 2003. It was the first country to introduce WIIs at a commercial scale and is still the one which covers the highest number of farmers. The first implementation in 2003 was initiated by the private sector; more precisely, it was a joint initiative of the insurance company ICICI Lombard and the microfinance institution BASIX, with the help of the Commodity Risk Management Group (CRMG) of the World Bank (Hazell, 2010). It began in Andhra Pradesh, covering groundnut and castor oil plant against drought on three phenological phases of the crop. This programme expanded over time and covered, in 2008-09, around 10,000 farmers over 8 states in India. On average, during the six years of operation, 15% of farmers received an indemnity and the loss ratio (ratio of the sum of indemnities to the sum of premiums) amounted to 62% in 2010 and 48% in 2011. Despite those levels the demand grew, reaching more than 9 millions insured farmer in 2011.

A second programme, a public one, covers a much higher number of farmers (1.6 million in 2009), it is called the Weather Based Crop Insurance Scheme (WBCIS). For the large majority of them (around 90%), insurance was compulsory since it was included in a package with a loan for agricultural inputs. Premiums are subsidized up to 80% by central and state governments, depending on the crop. As a consequence, the loss ratio amounts to 0.7 if calculated on the unsubsidised premium, versus 2.3 with the subsidised one, according to Chetaille et al. (2011).

Despite the low premiums actually paid by the farmers (less than US$ 5 per acre, Giné et al., 2007) there was a low observed subscription rate when premiums are not

[1] More recent reviews now exist, for instance in the case of India, the unique large scale market of individual index insurance, two quality reviews were released since that time (Giné et al., 2010 and Clarke et al., 2012).

subsidised, especially when compared to Mexican entirely subsidies premiums (with 22% of the national maize production insured). This somewhat disappointing result led to statistical studies about insurance take up and especially its determining factors (Cole et al., 2011, Giné et al., 2007 and Giné et al., 2008, cf. section 1.2.2 and 1.2.3).

1.1.2 Malawi

In Malawi, two projects jointly offering a WII with a credit for certified seeds were run by the Insurance Association of Malawi in association with a cooperative of local growers. The initial objective was to limit loan default payment, which precludes the development of these credits. Indeed, when the rainy season is bad, so is the yield and farmers are unable to repay the credit for certified seeds. For this reason, the maximum payout corresponds to the total loan value. The pilot program (launched during the 2005-2006 season) concerned groundnut producers of some regions (Hess and Syroka, 2005). The second was spread out over the whole country and extended to corn producers (2006-2007). The first round concerned less than 900 farmers and the second one about 2500 (of which 1710 were groundnut farmers, Barnett and Mahul, 2007). In the pilot program, drought was defined as less than 75 percent of the long-run average of cumulative rainfall over the rainy season. 13 of the 22 government-managed meteorological stations, showing satisfying quality standards in terms of missing values, were taken into account: they provided 40 years of rainfall data. Extensions in other South-East African countries (Tanzania, Uganda and Kenya) are considered (Osgood et al., 2007). Kenya is the most promising field in the close future due to availability and quality of meteorological data.

The impact of this program on income could not be estimated due to a good rainy season in 2006. The use of hybrid seeds rose compared to the previous years but, surprisingly, insurance had a negative impact on loan take up (Giné and Yang, 2009, cf. section 2.4.2). However farmers' limited collateral liability, their relatively high default rate as well as the complexity of the terms of the contract (bundled with credit) creating additional ambiguity for potential buyers, could have hindered adoption (cf. section 2.3.4). Less surprisingly, loan take up was higher for more educated and richer people in both the control and the treatment samples, a feature also found in many experiment on index insurance policies (cf. section 2.3.2).

1.1.3 Ethiopia

In Ethiopia, a pilot program was initiated by the World Food Program (WFP) during the 2006 and 2008 seasons, with a technical assistance from the Food and Agriculture Organization (FAO) and the World Bank. The premium was offered by the latter's major donors and the product was insured by AXA Re (now called PARIS Re). If any indemnity had been paid, the Ethiopian government would have redistributed the funding of the WFP, that holds the policy of this safety net, to about 60 000 households in 2006

(Barnett et al., 2008) that cultivate wheat, millet, cowpea and corn. The reinsurer and WFP used historical rainfall data from the Ethiopian National Meteorological Agency (NMA) and a crop-water balance model to develop the Ethiopia Agricultural Drought Index (EADI), which had a correlation of about 80 percent with the number of food aid beneficiaries between 1994 and 2004. Analysis of the historical data revealed a one in 20 probability of catastrophic drought in Ethiopia, as occurred in 1965, 1984 and 2002.

The index was based on the cumulative rainfall, computed with a network of 26 meteorological stations across the country. Long run data required for risk assessment were computed from interpolation of satellite and elevation datasets along 43 years longitudinal data across 80 areas, produced by the FEWSNET program. The complex annual rainfall pattern in Ethiopia pointed out the necessity to go thoroughly into growing strategies. In some regions there are two distinct rainy seasons, which induce two possible farming strategies depending on the earliness of the first one. Farmers can either choose to sow a long-cycle crop and hope to benefit from spring's rains or two different short-cycle crops.

In 2009 individual WIIs pilot projects were run in Ethiopia where the insurance market is developing, currently composed of one public and 10 private firms. One such example is the Horn of Africa Risk Transfer for Adaptation (HARITA) project in the Tigray region, designed by the International Research Institute for Climate and Society (IRI, Earth Institute, Columbia University) and launched by Oxfam America, the Rockefeller foundation and SwissRe. It is based on satellite imagery data. A second one was undertaken in the Oromia region supported by the WFP. Both projects directly target growers.

1.1.4 Other pilot projects and related literature

Institutional index insurance, as the Ethiopian one, covering governments against major spatially covariant shocks, were also launched in developping countries. It was the case of 16 Caribbean countries (2007) covered against natural disasters (hurricanes and earthquakes), in Malawi (2009) were the governement contracted an insurance, at the national level contrarily to the above-mentionned individual insurance, based on a production index for maize based on weather stations data, in Mexico (2003) against major droughts and in Mongolia (2009) against major livestock losses.

Small scale individual-level index insurances were also developed in China (2007), Ethiopia (2007), Rwanda (2009), Tanzania (2009) and Thailand (2007) and discontinued or only attained pilot stage in Kenya (2 launched in 2009), Indonesia (2009), Madagascar (2007), Nicaragua (2008), Philippines (2009), South Africa (2007) and Ukraine (2005). Updated exhaustive reviews of passed and present WII experiments can be found in Hellmuth et al., (2009), Hazell et al. (2010), DeJanvry et al. (2011).

1.2 Indices

1.2.1 Meteorological indices

Some products insure against cold temperatures or frost (South Africa), others insure against excess water during harvest (India, Nicaragua, Rwanda and Tanzania) or against floods (Indonesia and pilots in Vietnam and Thailand). Here, we focus on the most common dommageable phenomenon which is also the most relevant for the sudano-sahelian zone.

Basic rainfall indices

Cumulative rainfall during the growing season (which, in the tropics, typically corresponds to the rainy season) is the simplest quantifier of water availability. However, the impact of a lack of rain depends on the crop growth phase. Hence, in practice, the growing season is often split in several sub-periods and an indemnity is paid whenever a lack of rain occurs in one of these sub-periods. The amount of rainfall that triggers the payment of an indemnity (the strike) as well as the amount of indemnity differ across the sub-periods and are based on agro-meteorological knowledge. Moreover, very light daily rains (typically <1 mm/day) and daily rains exceeding a given cap (60 mm per day in most Indian insurance schemes) are generally not taken into account in the cumulated rainfall. Indeed, very light daily rains generally evaporate before being used by the plant, while rains exceeding a given cap run off and cannot be used either. Such simple indices were applied in India and during the first Malawian experiment. Those indices were also used in the Ethiopian scheme where payments were triggered by a low cumulative rainfall from March to October, compared to the 30-years average. Crop specific indices were computed by weighting 10-days periods cumulative rainfalls according to their relative impact on yields.

The Available Water Resource Index (AWRI: Byun et al., 2002), based on effective precipitations of the previous days, is a slight improvement on the cumulative rainfall. It is roughly simulating reduction of soil water stocks due to runoff, evapotranspiration and infiltration. Reduction is represented as a weighted sum of previous rains on a defined period (often 10 days) with time-decreasing factors.

Water balance and water stress indices Water balance is computed by subtracting water losses to gains for a specific location on which the potential evapotranspiration (PET) is defined. Precipitations provide water whereas losses are principally due to draining and crop evapotranspiration. PET calculation (Allen et al., 1998) is made through more or less direct methods using quite specific data[2] for a good evaluation, or can even

[2] PET is more precise than available rainfall for crops but they requires a lot of data such as solar radiation, wind speed, daily minimum and maximum air temperatures, relative air humidity, latitude, longitude and altitude, and cloud cover once an hour if possible. Soil type has also to be checked once individually for each region considered.

be measured on the field with lysimeters. Water stress indices are based on the idea that crop yields are proportional to the satisfaction of crop needs for water resource.

The WRSI (Water Requirement Stress Index) is the reference water stress index. It is defined as the ratio of actual evapotranspiration (ETa) to maximum evapotranspiration (ETc). ETa corresponds to an estimation of the quantity of water actually evaporated while ETc corresponds to the quantity of water that would evaporate if the water requirements of the plant were fully satisfied. This index was developed by the FAO and used in different WII schemes in India and in Malawi, computed on a 10 days period. FEWSNET improved it by taking into account water excess.

Kellner and Musshof (2011) use water capacity indices and compare them to common precipitation-based indices in the purpose of sheltering Eastern Germany farms against drought risk by calibrating WII for different crops. They find that risk reduction is higher due to a reduction in basis risk when using such elaborated indices. However, as mentionned by Hill and Robles (2010) such models have been modeled and tested in temperate climates for crops grown under ideal conditions on large plots that are not intercropped (Allen, 1998).

Phase-specified policy and sowing date issues

Since crop sensibility to water stress depends on its growth phase, most of the insurance contracts consider those phases and take in account different references values of WRSI as triggers, corresponding to different levels of crop water needs depending on the phase considered. There is generally 3 to 7 depending on the crop: sowing and establishment, growth and flowering, yield transformation phases and harvest. For instance, it was the case of the Indian and the Malawian (for groundnut) individual insurance experiments (cf. 1.1.1 and 1.1.2) distinguishing 3 major crop growth phenological phases (growth, flowering and yield transformation). For tobacco, the growing period was divided in 17 blocks of two weeks in the case of the Malawian WII. Rainfall level of each block is compared to the crop requirement for this particular growth stage and included in the weighted sum in order to compute the index corresponding for the whole period.

The major impediment in such a design implementation is the need for a sowing date (or thin period often called sowing window) to trigger the beginning of growth cycle. All the previously mentionned indices would be better predictors of yields if they are calculated using the actual sowing date (or a sowing window) to trigger the beginning of the growth cycle. However, inquiring after actual sowing date can be very costly (as discussed in the case of cotton in Northern Cameroon, in the chapter V of this thesis). Farmer's statement would indeed induce a transaction cost, limiting the scope of the product. Hence, in practice, especially in India and Malawi, the sowing date used to determine the crop growth phases is imposed by the insurer (a fixed period in Malawi and triggered by the occurrence of a precise cumulative rainfall level in India).

Imposing an arbitrary sowing date or window in the insurance policy increases the basis risk hence reduces the benefit of the WII. It is nevertheless efficient when dealing with homogenous and predictable growing practices. For instance, it was set between 1^{st} November and 20^{th} January in the Malawian experiment. In this case, providing an annual weather forecast (cf. 1.3.3.3) and a precise analysis of farmers practices should ideally precede the design and supply of insurance

Finally it could be simulated (as in Mahul et al., 2009) or chosen by farmers for instance among a list periods specified by the contract. The issue of setting a sowing window is tightly linked with the determination of the beginning for the rainy season. We discuss the importance of acutely forecasting the onset of the rainy season for growers in section 1.3.3.3. Recent research in West Africa favors an indicator of spatial coherence of (in general two) rainy days in different places located nearby (Sivakumar 1988 and Marteau 2011). Such criterion could then be used to simulate ex post the farmers' sowing decision using rainfall data. Heterogeneity of growing practices and/or beginning of rainy season within the area could therefore be an obstacle.

Drought indices

Those indices use temperatures and rainfall to determine air and/or soil dryness. The Selyaninov drought index, also called Selyaninov Hydrothermal Ratio, and the Ped index only captures the air dryness. Both have been used by Breustedt et al. (2004) in an ex-ante WII scheme study designed for Kazakhstan. Their calculus has the convenience of only requiring rainfall and temperatures data. The Palmer Drought Severity Index (PDSI: Palmer, 1965) was used for the study of an insurance scheme in Morocco (Skees, 2001). It requires temperature, latitude, water retention capacity of soils and precipitations data, usually on a ten day basis.

1.2.2 Satellite imagery data

Satellite imagery data allows the computing of leaf area index (LAI) or other vegetation indices such as the Normalized Difference Vegetation Index (NDVI). The latter evaluates crop canopy photosynthesis - more precisely light absorption - calculated from the difference between near infrared (NIR) and red beams (RED), divided by their sum: NDVI = (NIR-RED)/(NIR+RED).

The NDVI can barely discriminate between pastures and cultivated areas and it is calculated with a delay period because of the potential presence of clouds. It is quite well adapted to biomass assessment but not to yield assessment. This technique is thus being more and more frequently used for global food crisis early warning, livestock management, and forecast of forage production[3]. Besides improvements in such fields are very quick so that imagery resolution increases every year with freely available data recorded since

[3] Implemented by Agriculture Financial Services Corporation (AFSC) in Canada, Spain, and Mexico (Hartell et al., 2006), by the Word Bank in 2005 in Mongolia (Mahul and Skees, 2008) and for livestock insurance in Kenya described in Mude et al. (2010).

the year 1981 (for a 8 km resolution). However, delays in processing, homogeneization from difference sattelites data source and validation from research scientists, of MODIS data (the main source for such indices) render them inadequate for real-time drought monitoring. However, there are some near-real-time access to processed products such as eMODIS from USGS EROS as underlined by Anyamba and Tucker (2012) and discussed in the chapter V.

1.2.3 Mechanistic crop models

Mechanistic and dynamic models simulate crop physiological growth depending on available environmental factors (cf. Akponikpe, 2008 for an exhaustive review). Their precision in yields estimation is greater, but they need very detailed input data, particularly time series at the plot level. Such data are rarely available for large areas, especially in developing countries.

The DSSAT model is used by Osgood et al. (2007) in East Africa and Diaz Nieto et al. (2005 and 2012) in Nicaragua. It is however difficult to use such complex models because of a high sensitivity to parameters calibration and relies on the implied theoretical relation between yield and water. On the other hand they can be used to assess the shortcomings of other methods such as an unfavourable simulation of water stress. They may allow for yield simulation under higher levels of inputs than actually used by the farmers, which may be useful since WIIs create an incentive for such intensification that is unobservable ex ante (as discussed in the cas of Niger in the Chapter II).

1.2.4 About the use of complex models

First of all, designing a marketable WII is a challenge because very complex trade offs are at stake: we want it to limit basis risk by choosing an adapted index and the shape and calibration of the contract but do not want to fine tune it which would make it to hard to understand and to assess.

As mentionned earlier in this section Kellner and Musshof (2011) argue that using water capacity indices improves the outcome of index insurance. They however do not mention overfitting issues (we will discuss in broader terms in the chapter 4), that are to be worsen in the case of a complex index, since optimization of index parameters could artificially increase insurance gains. Moreover, the calibration of area-specific parameters in the calculation of the index value leads to relative subsidization (taxation) of areas endowed with soil that are less (more) suitable to the cropping system or more (less) prone to drought. We show in the chapter 5 of this thesis that it is what happen when dealing with heterogeneous areas in term of the agrometeorological relation.

The use of mecanistic models also poses some problems if someone want to use directly the forecasted yield as an index. It would indeed make the indemnity depend on farmers choice such as the varietar, the crop management techniques or on structural parameters such as the soil type and its retention capacity. It will then lead to moral hasard issues in the first case and to a subvention of plot that are badly endowed. Mecanistic models thus should only be used in order to extract the role of weather variable on yield, which is probably not such an easy task.

1.3 Insurance policy design and calibration

1.3.1 Typical indemnity schedule

Typically the average contract is a linear one. There is, however, no evidence for choosing such a contract (Kapphan, 2011), and a simple lump sum contract could be more efficient (Gelade 2012) when there is a fixed cost associated with each indemnification. The standard indemnity schedule is defined in the related literature by three parameters (λ,S,M), as brought forward by Vedenov and Barnett (2004). Insurance indemnities are triggered by low values of an underlying index that is supposed to explain yield variation. 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, which correspond to a lump sum transfert.

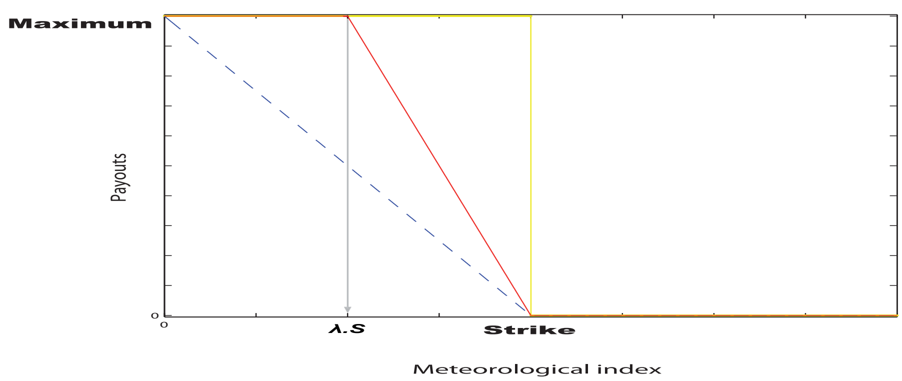

Figure 1: Usual shapes of WII policies.

In many WII experiments, the indemnity schedule is more complex. In particular, as explained above (section 2.1.3), partial payouts are calculated for each crop growth phase, and the total indemnity is the total of these partial payouts. This design is based on the hypothesis that investment returns could be annihilated at every growth phase. It is the case in Malawi (Osgood et al., 2007) and Senegal (Mahul et al., 2009) and many schemes in India. A maximum insurance payout is defined for each growth phase and the sum of insurance payouts can also be capped for the whole growing period. De

Bock et al. (2010) introduced a second strike level in order to increase acceptance of the product by increasing the number of indemnified growers at low cost for the insurer. Insurance policies also could provide different hedging level for a given cultivated area, in the purpose of inciting farmers to reveal their level of investment. High intensification growing practices indeed relies on higher costs (and correspond to a higher level of risk taken) and thus need a higher level of coverage.

1.3.2 Optimization of policy parameters

We review here the methodology for designing the potential WII products under standard (Von-Neumann Morgerstern) expected utility[4].

In most cases, the indemnity schedule and the parameters are set without a formal optimization process, on the basis of expert knowledge. Typically, the strike will be set according to agronomists' views of under what level rainfall starts to be a limiting factor for crop yield, and the maximum payment may be set at the total value of inputs (fertilizers, seeds, pesticides...). In this case the strike is set according to a theoretical relation linking yields and water availability as in Vedenov and Barnett (2004).

In some cases, some of the parameters at least are set following an explicit optimization process. The function to optimize differs across authors. Some maximize an expected utility function with a given risk aversion, e.g. a Constant Relative Risk Aversion (CRRA) function in Berg et al. (2009). Others minimize the semi-variance[5] of insured income[6] as in Vedenov and Barnett (2004). Semi-standard deviation (also called Root Mean Square Loss, RMSL) can alternatively be considered if large losses are not to be overweighted compared to little losses. Finally Osgood et al., 2007 minimize the variance of basis risk i.e. the difference between payouts and expected losses, the latter being defined as an inferior quantile of the yield distribution simulated with the DSSAT crop model.

To wrap up there are 2 major categories of objective functions. A first type only ensure that the insurance scheme reaches the risk minimization objective and lowers the risk level (i.e. income downside variations). It includes semi-variance and its squared root, which minimize downside loss, only taking the lowest part of the outcome distribution into account. The second type (e.g. CRRA and mean-variance) take into account the cost in terms of average income. They allows to quantify and compare the reduction of risk to its cost in terms of average income, due to the presence of a positive loading factor.

[4] The next section below is dedicated to the assessment methodologies and the case of subjective beliefs will be discussed in the third section of the introduction (section 3.2.3.5).

[5] Semi-variance is the squared difference of income inferior to the long-run average income, relatively to this long run level.

[6] Income after insurance is the observed income plus indemnity minus premium

1.3.3 Basis risk and index choice

Definition and causes of basis risk

The basis risk, *i.e.* the imperfect correlation between the index and yield, is a combination of two factors: first the spatial variability of weather (cf. section 3.2.5.2) that makes it to costly to assess in each precise point where the yield is observed and, second, the unperfectibility of weather indices.

The word 'basis risk' comes from finance and more precisely from the options theory, used for the study of future markets including weather derivatives. The base is the difference between the future value in the central (terminal) market and the one observed in a remote area. This difference is composed of both a stochastic and a deterministic component. The latter is explained by the distance to the terminal market and the cost of crop storage, decreasing as the term get closer. The stochastic part of the base creates a risk called basis risk.

In the case of index insurance, basis risk has 3 different sources. First, the spatial basis risk comes from the the distance from where the observation of the index is done to the place where the crop is grown. Second, there is always a lack of correlation between the yield and the index, for instance due to non meteorological shocks (locust invasions, pests, diseases...) in the case of WIIs. Lastly, the idyosynchratic basis risk comes from the difference of productivity between heterogeneous farmers that do not put the same effort into production, do not use the same practices etc. We formulate better and apply such distinction in the chapter V.

Typology of basis risk

We can distinguish two kinds of particular basis risk in WII designs, with regard its effect on the insured ones. The first is the probability to give an indemnity to farmers that do not need it (false positive or 'false alarm', we will call it type I basis risk) is costly for the whole indemnified farmers (more precisely those paying premiums). It should be limited if the index is well designed, however in many case it remains.

The second type (type II basis risk, false negative) is a bad outcome without an alarm, also called missed crisis. The second type error is supposed to be worse regarding the demand of WII, especially when combined with the first type. As shown by Clarke (2011) index insurance with significant basis risk can indeed lower utility in the case of a concave utility function. In that case the premium is paid when there is no signal for a bad situation, the exposure of the insured to risk could even increase since the outcome is worsen by the insurance (bad outcome minus a positive premium).

Minimizing the basis risk is the main criterion to compare those indices. The correlation between yields and index values is the simplest way to deal with such choice (as done in Carter, 2007), but more complex objective functions exist. In order to improve the attractiveness for farmers it is fundamental to choose a utility function in order to estimate the cost of a lack of correlation between yields and index values for low yields, i.e. for situations in which an indemnity should be paid (as discussed in the fifth chapter).

However, complexity limits the transparency and acceptability of WIIs and data availability is also often limited, especially in developing countries. Thus there is a trade-off between index transparency, readability for farmers, data availability and simplicity on the one hand, and the index ability to reflect low yields (or minimize the basis risk) on the other hand. If the insurance target is the farmer, simplicity is important, but if the target is a financial institution willing to insure its agricultural portfolio exposed to weather shocks, the product can be more complex.

1.3.4 Ex ante validation of index insurance policies design

As mentionned earlier, many ex post evaluation of WII experiments recently took place. It is however very coslty to implement those experiments and then run rigorous ex post impact analysis, especially when compared to ex ante analysis (Harrison, 2011). Moreover, designing an optimal insurance contract requires an assessment of farmers' interest and product accuracy before launching it, such necessary step is often spared, probably due to data, time and budget constraints. Ex ante assessment could even though avoid miscalibration and allow to fit better farmers need, which seem to be a critical necessity to convince farmers of WII relevance.

Testing the WII policy design may be done by computing the three parameters of the policy design and a premium level (total indemnification multiplied by the loading factor divided by the number of policies sold) on, potentially detrended, historical data. It might alternatively be done by fitting a statistical distribution function on the index time series and then run simulations to get an idea of future index realizations. Working on historical indices time series is called the Historical Burn Analysis (HBA) method and the simulation of meteorological index series is the Historical Distribution Analysis (HDA) also called index modeling method. Both methods are investigating different properties of the policy, the first one helps in parameterizing and assessing the contract pooling capacity on historical data while the second allows to test the robustness of a given contract over a long time span.

HBA method

Running policy on index and yield historical data is the only way to test a policy design a posteriori. Studying historical yield data however annihilates any endogenous impact of the policy such as the increase of average yields that could induce intensification (as shown by Hill and Viceisza, 2009) or other riskier strategies due to the pooling of risk among farmers (section 3.2.1.1).

The analysis of the distribution of moments of the index allows the future insurance payouts to be foreseen without making any assumptions on distribution function's parameters, as it is the case in HDA analysis (cf. next paragraph). Minimizing the difference between losses and payouts by a simple optimization technique is the best way to find an optimum value for any parameter. Such optimization should be done on a distinct sub-sample to avoid in-sample calibration leading to over-fit the sample data that artificially enhances the results.

Dealing with ex ante impacts, cross validation seem necessary because it is useful to test the stability of the calibration on different samples if data is sufficiently proficient. There exists different sampling techniques separating training and validation data such as cross-validation, but they requires a minimum of spatial and temporal data. Among k-fold cross validation techniques a way to deal with over-fitting with short time series is to use a leave-one-out (Berg et al., 2009, also often called jackknife). In such method, calibration of parameters is done n times: on n-1 observations and tested on the n^{th} observation left out of calibration sample.

HDA method

The quality of probability evaluation of indemnifications depends on the length of data series because high risk associated with low occurrence are very difficult to apprehend. Low probabilities / high risks (fat-tailed) distributions will thus be preferably treated with the HDA method.

Such method is worthwhile for testing the future prospects of a policy scheme. It is useful to test it in the long run, even if index data are not available on such time span for example checking for supplier solvability i.e. sustainability of the supply. Fitting a distribution function on a meteorological index allows the assessment of future WII outcomes through Monte-Carlo simulations (Hartell et al., 2006). Rare events, even if not present in the historical series, might be simulated and the specificity of the underlying density function can be better apprehended. Moreover outliers will have less of an impact on results than they do in the case of HBA and confidence intervals can be assessed by running bootstrap or other statistical methods on those large simulated series. Fitting the underlying distribution is its major advantage but also the major impediment. Simulated data are indeed very sensitive to parameter calibration (Jewson, 2004) and there is thus a need for large time series on index data. In practice designing an insurance scheme requires about 20 or 30 years of data (Jewson, 2004 and Woodward, 2011) depending on its quality and the presence of long-run trends (cf. section 3.2.5.1).

The only formal comparison of the accuracy of the two methods seems to be a working paper by Jewson (2004) who concludes that HDA is significantly better than HBA when there is little uncertainty on the statistical distribution assumed in the HDA method. Both methods seem complementary and should ideally be run simultaneously for policy design, it has however never been the case in the existing literature.

1.3.5 Loading factor calibration

The insurance premium is higher than the expected indemnity (except if the insurance is subsidized) since it includes the administrative costs as well as the cost (load) of the risk taken by the insurer, *i.e.* the loading factor[7]. We only discuss the second aspect here.

The cost of the risk for the insurer decreases with the diversification of the portfolio of the insurer that could layer risk insuring different clients or regions (Meze-Hausken et al., 2009). It is also worth mentioning that reinsurance is able to cap the risk taken by national insurance companies who suffer from covariance within their portfolio. Finally a key element that affects the loading factor is the availability of historical data. For example, the loading factor for a policy which uses a new weather station will be higher than that for a policy with a long series of historical data. Aware of those limits two methods can be derived for evaluating the additional cost of risk taking (Henderson, 2002):

- The Sharpe ratio margin is proportional to cost standard deviation (σ(I), with I the indemnifications) for the insurer:

$$\alpha \times \sigma(I) \tag{1}$$

  Where σ is the Sharpe ratio. It is less adapted for HDA, in which standard deviation is a parameter.

- In the Value at Risk (VAR) this margin is proportional to a risk of defined occurrence probability. For example risk cost valuating at the VAR_{99} cost of events that occurs with a probability of less than 1%:

$$\beta \times [VAR_{99} - E(I)] \tag{2}$$

The latter method is more adapted to high risk with low probability (such as extreme weather or the occurrence of natural hazards) but cannot be applied with HBA (cf. the two previous paragraphs) since the number of events is too low. An ex-post statistical analysis on a case study in India conducted by Giné et al. (2007) showed that a large part of the payouts are due to extreme events: half of them in that case were due to the worse 2% climatic events. According to Hartell et al. (2006), α is chosen between 15% and 30% and β between 5% and 15% (and between 5% and 7% according to Hess and Syroka, 2005 and Osgood et al., 2007 who draw on WII case studies). For instance, in the case of Malawi, the VaR method applied with a factor β of 5% leads to an increase of 17.5% of the premium over the actuarial rate (no risk loading) and a final premium rate of 11% of total indemnifications (Hess and Syroka, 2005). However, due to sharp competition among private insurers, the actual rules for fixing the risk loading are very hard to assess.

[7] Also known as gross-up factor or charging rate.

2 Challenges and research questions

We will focus here on individual level WII schemes (as opposed to institutional ones as it was implemented in Ethiopia at the national level) which are concerned in the chapters IV and V. The recent but quite prolific academic literature on index-based insurance indeed raised several very interesting questions.

2.1 Low technology adoption under climate risk

We will try, in this section, to show the channels trough which risk could hinder farm capitalization leading to lower yields. It can also be seen as theoretical grounds that lead to think *a priori* that WII have high potential returns.

We will try to overcome the complexity of the topic coming from the interlinked relations bewteen the three main characteristics of smallholder farming on which we shed light in this essay: tied budget constraint and lack of access to markets, the presence of risk and a low intensification partly due to low technology adoption.

The existence of a yield gap in Africa is widely accepted by academics[8], however the question about the best mean to trigger intensification and productivity largely remains unsettled. There are indeed numerous hypotheses for explaining such gap with other developing and emerging countries. Risk is one among them and weather is only one of its sources (Fafchamps, 2010), it however gained great attention in the scientific community[9]. Such shocks are indeed known to have ex ante and ex post impacts on farming decisions. Poor level of wealth probably prevents farmers from implementing risky strategies that are more productive in average. Binswanger and Rosenzweig (1993) evaluate at 35% the average profit loss for the poorest quartile of Indian farmers undertaking low risk/low yields productive choices, partly due to risk aversion.

African smallholder farming shows very low intensification (excepting the cotton case discussed in broader details in the two firsts chapters): we will thus describe the two main recent potential explanations of this fact in the recent literature.

We will focus on subsistence constraint and timing in technology adoption. Both aspects are of primary importance for WII or other risk management strategies that reduces the risk before the cropping season without bringing distorsions. We will see that in spite of heterogeneous returns to technologies, they could play a great role in technology adoption.

[8] See Udry, 2010 for a review.

[9] See for instance Udry (1995) concerning savings, Dercon (2004a) concerning education and Maccini and Yang (2009) concerning health issues.

2.1.1 Subsistence constraint and poverty traps: the role of risks

Poor households face a double constraint constituted of a tied budget (limited access to credit market) and a subsistence imperative. In order to meet minimum nutritional needs, households often under-invest in productive capital, including in human capital through health and education expenditures (see Collins et al., 2009 for anecdotical evidence).

There is a large body of literature on poverty traps (Bowles, Durlauf and Hoff, 2006, and Dercon, 2003) and some exploring the potential role of heterogenous capital detention on the existence of poverty trap (for instance Eswaran and Kotwal, 1990 on risk averse behaviours and land detention and Rosenzweig and Wolpin, 1993 on oxen detention and consumption smoothing in India).

It has so far proved very difficult to find convincing empirical evidence of poverty traps (e.g., Jalan and Ravallion, 2005), except for the often quoten example of Rosenzeig and Binswanger (1993). A possible reason for that is the heterogeneity of threshold among households and the complexity of the assessment of a multidimensional vulnerability, showing some psychological as well as qualitative aspects.

Some evidences however seem to go in that direction. Reardon and Taylor (1996) found that droughts increase poverty for the poor disproportionately, as they rely more heavily on crop income. The resulting liquidation of assets makes them even more vulnerable to future droughts. Lybbert and Barrett (2007) showed the same type of consequences concerning herd management and stochastic shocks. They highlight the presence of a threshold effect due to multiple equilibria in herd size. Barnett et al. (2008) reviewed such mechanisms and their crucial role in designing index based risk transfer products.

Facing risk creates an incentive for poor households to stock non-productive subsistence assets (food) with low-return and low-risk (Zimmerman and Carter, 2003, cf. section 3.2.4.1 for a short review of the impact of other informal risk coping strategies). Zimerman and Carter (2003) show the substituability between unproductive (stocks) and productive assets (land, livestocks) in a theoretical model and apply it to Burkina Faso. The first type of asset being more easy to sell in the case of a negative income shock and thus to play the (consumption smoothing) role of a buffer stock. This is to our knowledge the only theoretical model (with the one from Thorsen and Malchow-Möller, 2000, both using the graph theory) to consider states of the nature in which consumption (and thus utility) is zero for instance when it is below the subsistence level and thus able to deal with individual poverty trap dynamics. Hoddinott (2006) however put into question the accuity of the distinction between asset smoothing and consumption smoothing and finds that Zimbabwean households behave as if a pair of oxen represents an asset threshold below which they strive not to fall.

Concerning the dynamic of poverty trap, uninsured risk can affect the poor in two distinct ways: ex ante and ex post. Cai et al. (2010) find empirical evidence of an endogenous ex ante effect of insurance in China, where formal insurance increases farmer's tendency to invest in risky sow production. However the only framework developped to asses ex ante the impact of WII on such dynamics is the work of DeNicola (2011). It uses a mathematical programming model of a farm management with a WRSI insurance calibration design.

This academical debate also echoes in other spheres and one major point made by development practitioners concerns household farm management and intra-annual consumption smoothing or warrantage (harvest stocks in kind used as a collateral for cash credit). It allows to hedge farmers against intra-annual price variations. The first had an echo in the research area when mandatory or 'commitment' savings and warrantage has been proven to be quite efficient (for instance in a randomized experiment ran in Malawi for tobacco growers by Brune et al., 2010). Their great simplicity also argues in their favor.

2.1.2 Timing of shocks and investment opportunities

Most investments in agriculture has to be done before or during sowing (some fertilizers can still be applied during the growing cycle), period that follows the dry season, corresponding to the most critical period in terms of liquidity constraint. After the lean season, farmers are endowed with the lowest seasonal income stock: on-farm income comes from irrigated 'off-season' vegetables and/or legumes; and little rainy season crop harvest if there is two rainy season as it is the case in Ethiopia. It involves inherent difficulties for investing in that period, at least in absence of credit market or safe saving mechanisms: bank accounts, mandatory savings or warrantage.

The timing of shocks with regard to investment decisions seems crucial. Udry (2010) shows that household that face risk realized after input decision will invest under the optimal level 'sacrifying expected profits in exchange for more certain return'. Even though it is the case for most idiosyncratic shocks, such as weeds, pests and even some labor supply shocks, and covariant shocks, such as weather shocks and price fluctuations. This is coherent with the results of Duflo, Kremer and Robinson (2003) who run a randomized controlled trial (RCT) on the treatment by the Savings and Fertilizer Initiative (SAFI: a commitment device for farmers), finding that farmers take up this program when it is offered at harvest time, but not later.

2.2 Empirical evidence of a low weather index-based insurance take up in developping countries

Current research shows that the low (and price-elastic) demand for rainfall insurance raises doubts about the potential for this type of insurance as a general solution for all poor agricultural households to manage their risks (Macours 2012). The very low effective take up of weather index-based insurance by individual farmers indeed question the of theoretical estimation of a high return of such policies (cf. previous section 3.2.1).

Actual take up of WII experiments are very low: from 5% in 2004 analysed by Giné et al., 2008 in Gujarat, India to about 27% for the same sample of Indian farmers in 2006 as analyzed by Cole et al., 2011, in spite of a very high estimated potential. For instance an average gain of 17% of the income level in the long-run according to the calibration of DeNicola (2011) in the case of the Malawian experiment which was only purchased by 5% of farmers (Giné and Yang, 2009). Ex ante demand, estimated by willingness to pay for WII is also very high: Sarris et al. (2006) found that over 55% of all households surveyed would not purchase rainfall insurance with a positive premium in Tanzania. Sarris et al. (2012, ongoing) found that about 88% of Ethiopian household express interest in index insurance contracts and about 42% in a different study (Hill et al., 2011).

2.3 Potential determinants of the low weather index-based insurance take up

Rosenzweig and Wolpin already concluded in 1993 that the availability of weather insurance would have little effect on the well-being of Indian farmers. There are however two major limitations to that conclusion. First, the authors assume that even when households are hit by a large negative shock, they are guaranteed a minimum level of consumption. Second, the analysis focuses on understanding the process of accumulation of bullocks, which are considered as both production and saving assets. Since households own a maximum of two oxen and one water pump, Elbers et al. (2007) warn that the low level of heterogeneous variation in the farming inputs data may lead to an incorrect estimation of the structural parameters.

We will review here different mechanisms, raised by a much more recent literature, to explain the evidence of a low WII take up rate.

2.3.1 Price elasticity, budget constraint and time inconsistency

Only two recent experiments showed a relatively high take up level. The first is the Harita project (36% of buyers) where it was freely allocated with other products (Norton et al., 2011). The second, a recent experiment from Karlan et al. (2012) tests for different subsidization level, and find that at least half the acres were covered and even more, up to 100% for an insurance priced at the actuarially fair rate. Those results argue in favour of a high elasticity to insurance price (premium subsidization level) variations. However still some fair rate insurance experiments (the individual scheme in Malawi for instance) do not find enough buyer which suggest that there are also other reason for non buying those products. More generally, only a small proportion of farmers buy the insurance offered, the purchasers usually buy the smallest coverage offered and the poor farmers who would *a priori* benefit the most are not usually among the purchasers.

The most simple explanation for low take up rates could be the credit constraint. It was validated in the field by Cole et al. (2011) who found that households with randomly assigned endowments (about 80% or more of the insurance premium) are about 40 percentage points more likely to take up the insurance. Cole et al. (2011) argue that liquidity constraints do matter because they observe that the big endowment has a larger effect on poorer individuals, for whom liquidity constraints are more likely to be binding. Additionally, when asked about the main reason for not buying insurance, 'not enough funds to buy insurance' is the most common response. Likewise, Norton et al. (2011) found a significant decrease in the percentage of insurance buyers when they stopped distributing game endowments (from 99% to between 6 and 36% of insurance buyers). Measuring wealth in different ways, Gaurav et al. (2011) and Giné and Yang (2009) in India also found that the more wealthy are more likely to purchase insurance, although Dercon et al. (2011) do not.

Time inconsistency is also a potential explaination since it is difficult to ask poor people to pay up front a service whose benefit wil not be realized immediately. Duflo, Kremer and Robinson (2010) indeed show that time inconsistency is a major problem in the demand for fertilizer, and Tanaka et al. (2010) also found evidence of such inconsistencies in rural households in Vietnam.

2.3.2 Financial literacy and peers effect

A large body of literature points out the need to increase financial literacy such as probability apprehension in such products and the potential improvements that trainings could bring. The first reason given by farmers explaining the low take up is indeed the misunderstanding of the product (Giné et al., 2008). There is also strong evidences that technology adoption depend on financial education and observed literacy in Gaurav et al. (2011) and Patt et al. (2010).

Patt et al. (2010) compared the impact of traditional communication tools such as oral or written presentations of indexed contracts relative to role-playing games on two groups of farmers, controlling for their respective educational level. The experiment was designed for this purpose and took place in two different sites in Ethiopia and one in Malawi. They found a high correlation between insurance understanding and the desire to take up but no evidence of any superiority of role-playing games compared to oral or written presentations. According to the authors, the misunderstanding of insurance policies after the training could be due to an insufficient educational background.

The quality of the training is at stake: short 15-minutes explanations do not seem to be effective, or at least not nearly as effective as longer training sessions. Cole et al. (2011) compare marketing treatments: a video and a simple flyer. They found a little but significant superiority of the video treatment. A personal marketing intervention also had a great impact on take up (about 20%), even if the product is available to all household, suggesting that the personal relationship helps in reducing the trust gap.

Khan (2011) measures both the impact of educational interventions on the understanding of the insurance product as well as the impact on demand. To do so, he offers interventions on health insurance to a group of workers in Bangladesh, consisting of three sessions of a few hours, spread over three weeks. One month later, the author assesses the households' willingness to pay (WTP) for the insurance product and observe an increase in knowledge between pre- and post-treatment periods as well as between treated and control groups. Moreover, an 33.8% increase in the WTP is found for the intervention group.

Then, it seems that one should differenciate between the instructions about the complexitiy of the index-based insurance schemes that often are quite technically grounded and explaining the objective and the scope of insurance to households that never used some. Hill and Robles (2010) laboratory experiment show the challenge behind the trade off between complexity and basis risk. They show that, even in a context where insurance understanding is high due to a high differenciation in products and the help of endogenously formed risk-sharing groups, the level of basis risk, especially stemming from the high heterogeneity of farmers, significantly limits the demand. Debock and Gelade (2012) analyse the existing literature and conclude that while it is unclear whether financial literacy training can achieve to higher take up. There is definitely scope for current training methods to focus less on the technicalities of the insurance product and more on a broader understanding of its concepts. We will see below that understanding is also a crucial factor in renewing: financial literacy trainings, possibly coupled with a good follow-up can also have substantial effects in the long run.

As any technology to be adopted for the first time, the product is associated with a substancial uncertainty, that could be overcomed faster by using learning and network and peers. As pointed out by Hill (2011) it is a conceptual rather than a physical product and do not beneficiate every year to farmers, which probably even reinforces the underlying ambiguity, especially for less educated farmers. The literature brought up the critical role of farmers' interest and trust in distribution organisations and thus the need for utilizing existing networks among farmers (Cole et al. 2011; Patt et al., 2009 and Cai et al., 2009). The evidence also suggests that peers do have an important influence on the decision to adopt new technologies. By spreading information, buyers can increase the likelihood that a new technology will be purchased. Griliches seminal 1957 paper on the economics of agricultural technology adoption indeed suggests an s-shaped model of technological adoption where adoption begins with only a handful of people. Peers effects in technology adoption are a novel but prolific feature in the literature about technology adoption in developing countries (Conley and and Udry, 2010 and Duflo et al., 2009) and its impact on WII take up will probably be studied in deeper details along the coming years.

2.3.3 Basis risk and risk aversion and trust

It is generally held that farmers' aversion to risk affects the composition of their asset portfolio (see Rosenzweig and Binswanger 1993). It is therefore natural that we would expect demand to be increasing in risk aversion. Similarly, we expect demand to be declining with basis risk.

As a further extension, it is possible for farmer perceptions about the insured risk to differ from the information used to price the contract, in which case expected basis risk differs from the true basis risk. Mullally (2011) shows that such dissonance can negatively affect demand.

Strong and repeated empirical evidence from experimental studies reveals a result that seem quite odd at first sight: not only is demand for both indemnity and index-based insurance products low, but the likelihood of insurance purchases is negatively associated with measures of risk aversion in many contexts (Giné, Townsend, and Vickery 2008; Lybbert et al. 2010; Cole et al. 2011; Giné and Yang 2009; Galarza and Carter 2010 and Hill 2011). Cole et al. (2011) find that those who took the safest lotteries in a pre-survey are about 10 percentage points less likely to purchase insurance. Similarly, Giné et al. (2008) ascertain that risk-aversion decreases the probability to purchase the Indian rainfall index insurance by 1.1 percentage point, from a baseline take up of about 5 percent. Galarza and Carter (2010), in a field experiment where subjects can choose between safe projects, uninsured loans and insured loans, find a non-monotonic relationship between risk aversion and insurance demand. In particular, they find that highly risk averse individuals have a higher demand for safer projects (including either an insured loan or no loan at all) but that this relation is decreasing, that is, those individuals with the highest risk aversion would prefer the riskier project or not to purchase the insurance.

There could be some interactions between different factors explaining low observed take up rates. Theoretically, in the case of a WII, basis risk could be a sufficient reason for poor and risk averse enough household not to buy insurance (as pointed out the model of Clarke, 2011). Risk averse farmers fear basis risk that could even accentuate their losses in a bad harvest year associated with a 'good' index level as low risk averse farmers get a lower gain in certain equivalent. Cole et al. (2011), however, measure basis risk as the distance between the farmer's village and the rainfall station, and do not find a significant correlation between basis risk and demand.

This unexpected relation between risk aversion and insurance demand could also be explained by a lack of definition of the underlying risk. First, the aversion to uncertain events (or ambiguous, i.e. that are not associated with objective probabilities) is quite different from pure risk aversion (cf. the next section, 3.2.3.4). A lack of trust in the insurance supplying institution also can be seen as an uncertainty as shown by Dercon et al. (2011). They apply a model of limited trust to health insurance take up and found that, controlling for trust[10], slightly increasing risk-aversion for risk-lovers individuals seems to have a positive effect on demand but a negative one on highly averse agents. Moreover,

[10] Trust is defined here by the authors as a probability of default from the insurer as well as the unclear definition of what is covered by the contract. It is indeed important to differenciate between the trust in the product itself, the trust in the institution involved, and the degree of interpersonal trust of the individuals when considering insurances.

the effect of (random) price variations is stronger on the less trusting individuals.

We shall mention that the great heterogeneity in the result found across different studies might be explained by the specific features of the field works. Trust is indeed a complex feeling with diverse potential determinants, the institutions at stake, the way people are approached, and the running of the field may also play a role in the take up. Lastly, the impacts found could also simply be some reciprocal actions of farmers participating to programmes characterized by the disbursement of an endowment grant or any other (monetary or not) transaction; there is thus still room for other factors limiting WII demand.

2.3.4 Beyond expected utility: uncertainty and ambiguity aversion

The literature about uncertainty, as opposed to risk that could be associated with a probability of occurrence (Knight, 1921 and Keynes, 1921), lead to the emergence of the notion of ambiguity. It stem from the initial approach of Ramsey (1926) and DeFinetti (1927) about probabilistic beliefs[11] that became recently popular because it allows to explain some individual behaviours that are challendging the expected utility theory (EUT) framework, such as the famous Allais (1953) or Ellsberg (1961) paradox.

Climate, partly due to the complexity of its underlying mechanisms is in the realm of ambiguity rather than risk; meaning that while there is some information about the relative likelihoods of different outcomes, this information does not constitute a probability density function. Index-based products are indeed particularly subject to ambiguity, i.e. uncertainty about underlying probabilities, for targetted farmers.

As seen for risk aversion, effect of ambiguity aversion on WII take up is not theoretically straightforward. One could first argue that ambiguity averse growers would like to reduce weather ambiguity by buing WII. However since the index insured is uncertain, some ambiguity still remains on the insurance contract outcome, especially in the presence of basis risk that impede insurance to remove the risk completely. It is then difficult to distinguish the effect of uncertainty from the effect of trust, since beliefs will play a role on the perception of the insurance supplied (and thus on the level of basis risk). It is thus a potential lead for explaining divergence of take up in field experiments from the theoretically modelled gains of such products.

The effect of ambiguity aversion on technology adoption also depends on the effect of the technology on the perceived ambiguity. For instance, reducing ambiguity related to pest and disease, as in Barham et al. (2011), increase adoption if the technology reduces (more that it amplifies) ambiguity. Alary et al. (2011) show that ambiguity aversion should, in their framework, increase the level of self-insurance but lowers the

[11] Individual subjectivity leads to a misapprehension of probabilities, often leading to an overestimation of low probability events. Delavande et al. (2011) offers a recent review of methods for empirical assessment of subjective probabilities in developing countries.

level of self-protection, i.e. individual behaviours seen as risk mitigation measures (such as systematically using a seat-belt).

Ambiguity aversion impact on technology adoption and WII take up has been tested in a few studies. An experiment lead by Ross et al. (2010) in Lao republic showed that farmers' technology adoption seem to be hindered by ambiguity aversion more than simple risk aversion. This study is run in a very different region and considers many heterogeneous technologies. There are however other empirical evidence that point out the role of ambiguity aversion in risk management practices. Engle-Warnick et al. (2007) studied Peruvian farmers' decision to diversify and use new crops (assumed to be associated with unknown yield distributions) and found that ambiguity aversion is a factor for lower crop diversification and that risk aversion is not paying any role. The recentness of the fields and a lack of comparable studies however prevent from settling the question.

Alpizar et al. (2009) shows that farmers in Costa-Rica are more prone to take safer adaptation options (represented by insurance against natural hazards) when there is uncertainty rather than risk. Akay et al. (2009) found that Ehiopian farmers show the same ambiguity aversion that student samples and that poor health can play a role in such behavioural characteristic.

The only study that directly linked insurance take up to ambiguity aversion is the one from Bryan (2010). The author focused on index-insurance take up in Kenya and Malawi (using the data of Giné and Yang, 2009) and shows that ambiguity aversion lower the demand for WII even when controling for trust and risk aversion levels as revealed by farmers on a scale of 1 to 10.

2.3.5 Recency bias, hot-hand effect and subjective probabilities

Risk aversion also probably plays a role in technology adoption if considering that the Gollier and Pratt's (1996) theory - saying that households that endure losses due to one particular risk will update their beliefs and thus put higher probability on such events that those that did not - is true, as tested on an indonesian sample by Cameron and Shah (2011).

Rainfall patterns in the semi-arid tropics of West Africa exhibit no serial correlation (Nicholson 1993). Karlan et al. (2012) results are so far consistent with farmers who act otherwise. The results are consistent with salience, or recency bias, in which farmers who experienced a trigger event last year overestimate the probability of its reoccurrence this year and similarly farmers who did not experience a trigger event underestimate the probability of a payout this year. Galarza and Carter (2010) also found a 'hot-hand'[12] effect stemming from an minoration of the autocorrelation of the sequence of very bad years that could lead to take more risk after the occurrence of a 'bad' season. The authors

[12] Hot-hand and gambler's fallacy are respectively the overestimation and minoration of autocorrelation of a random independant and identically distributed (iid) sequence, often observed in gambling.

make a distinction with the recency effect, this effect being the bias towards overweighting recent information and underweighting prior beliefs. Subjective probabilities thus could have an impact on insurance take up and put into question the expected utility approach.

One important policy implication of such idea is that the take up could increase in the long run due to learning effect or simple reduction of ambiguity by integrating probabilities with outcomes. There is indeed empirical evidence of a greater probability to chose ambiguous options in repeated games more than in single-options game (Liu and Colman, 2009). As showed by Papon (2008) historical events could also have a great impact on the willingness to pay for reinsurance. The occurrence of a drought in the first years or before WII implementation thus could increase the willingness to pay for it. Arun and Bendig (2010) support this idea and show that the experience of specific hazards in the past, in particular the death or a severe illness of a household member or the inability to sell agricultural products in the past five years, increases the probability to use financial services in Sri Lanka. In contrast, Cole et al. (2011) and Stein (2011) do not find any clear evidence that having experienced a weather shock increases the uptake of insurance services.

The prospect theory of Kahnman and Tversky (1979) first make the hypothesis that differential utility due to a marginal increase of income is not the same shape in the gain and in the loss domain (reflexion effect). This loss aversion is backed by many empirical studies on smallholders in developing countries: for instance Gheyssens and Günther (2011) in Benin and Tanaka et al. (2010) who show that loss aversion (and not risk aversion) is correlated with low income in Vietnam. In top of the reflection effect, prospect theory also implies a biased weighting of probabilities that leads to underestimate bad outcome associated with low probability. Underweighting low probablities also seem to be verified in the context of farmers in rich as well as in developing countries. Sherrick et al. (2000) explored the rational behind rainfall beliefs and show that they are very poor for Illinois farmers and that it leads to understate (overstate) the likelihood of favourable (unfavourable) events. It leads the author to claim that it could lower the values of weather prediction found with common methods if recipients begin with less accurate prior beliefs.Liu (2008) studied the effect of risk attitudes on adoption of Bt cotton cultivar in China. She found that risk aversion prevents farmers to adopt early but that farmers overweighting small probability events tend to adopt earlier. It can be explained by the emphasize they put on low risk / high damages events that could have devastating effect on the production capacity.

However in the context of index insurance, the only study we found does not seem to validate that approach but the exact opposite. Clarke and Kalani (2011) actually find that insurance take up decisions in a game are better explained by the underweighting of extreme events, instead of the overweighting prescribed by prospect theory.

2.3.6 Heterogeneous returns

There are various reasons for explaining the very low actual demand for rainfall insurance in the pilots projects, one of them is the heterogeneity of risk aversion but it explains very little the observed heterogeneity in insurance demand. Spinnewijn (2012) proposes that heterogeneity in risk perception rather that direct aversion could complexify the current state of the framework.

There is a large, above-mentionned, body of literature exploring the potential role of heterogenous capital detention on the existence of poverty trap (for instance Eswaran and Kotwal, 1990 on risk aversion behaviours and Rosenzweig and Wolpin, 1993 on consumption smoothing). Recent articles focused on heterogeneity of farming conditions, in order to look deeper at individual factors for low technology adoption. Considering the average farmer can indeed lead to underestimate discrepancies between those that have large bufferstocks (such as livestocks), those that are more or less risk averse etc. Heterogeneity of agricultural practices (Zeitlin et al., 2010) could explain the high variation of yields observed in developing countries (the chapter IV of this thesis illustrates this stylized fact).

Suri (2011) tries to show how much heterogeneity of input return can explain its adoption among households without calling irrationality. According to the author, adoption depend on technology return and farmers' individual comparative advantage in a given technology. Farmers with high return could have great disincentives from adopting due to high unobservable costs (low supply, infrastructure constraints) as compared to farmers with low return that are more prone to adopt the technology. A third category emerges in that study, that is the marginal farmers, with zero return to the technology that continuously switch in and out of use from period to period. Such feature could partly be due to the particularity of the technology considered (hybrid maize) that have decreasing returns in time, since replanting seeds will lead to lower probability of detaining the the desired crop modified genes each year.

If heterogeneity in observed yields is not explained by weather spatial discrepancies, index-insurance will probably not able to help farmers to get out of poverty traps if it is not supplied with a high flexibility on the contract that would fit heterogeneous farmers needs.

2.4 Interaction with other risk management tools

The literature dinstiguishes between risk management (or mitigation: ex ante) and risk coping (ex post: dealing with a given income) methods following Alderman and Paxson (1992) and Dercon (2004b). Since Besley (1995) and Fafchamps (2003) already reviewed the literature on those informal methods, we only mention them briefly below. There is many ways to manage (income diversification and informal insurance) or cope with risks among them insurance. The results of recent RCT's treating about such tools are reviewed in Macours (2012).

We will review potentially complementary and substitute ex ante hedging tools, with a focus on the way they could be combined with WII implementation and their potential impact on WII demand.

One could also argue that offering insurance with complementary products, i.e. bundle it with credit or weather forecasts. Economies of scale thus makes administration costs, largely composed of screening and monitoring, drop and lower the product price. Distribution costs also could be limited if different products are supplied in remote areas by the same distribution networks, i.e. same agents of a unique micro-finance institution (MFI).

But it could also be argued that WII are competing with other risk pooling tools as it is stressed by the literature (Hill, 2011). One has however to recall the substitutability with informal risk management strategies (such as diversification) or with risk mitigation strategies such as infrastructures investments: for example irrigation projects that could be crowded out by insurance providing is also able to limit the scope of such products. It could also be due to the desincentive due to the fact that insurance is only supplied to unirrigated lands, as mentionned in the Mexican case studied by Fuchs and Wolff (2011a), that revealed very instructive. The authors also pointed out that only insuring a few crops could lead to lowering over-specialization leading to a lack of diversification (the crop choice as well as intercropping are among the most common risk management tool) in various crops and off-farm income. Less diversification means a decrease in the scope of the risk taken as well as it can lead to environmental damage since the crop insured are often high yielding varieties, grown with many inputs under monoculture, potentially deteriorating soil fertility.

2.4.1 Informal hedging methods

Even if often very costly, informal credit, storage and other informal risk management strategies, could be a substitute to insurance products, by being accessible to all households. Complementarity between formal and informal insurance was discussed very early (Arnott and Stiglitz, 1991). Supplying formal insurance to the poor could break existing ties and informal transfers (Bloch et al., 2008), such as family or friends. More recent works examine the precise relationship between those two aspects. Mobarak and Rosenzweig (2012) showed that indian farmers are less prone to use formal insurance due to the participation in informal networks, only if those networks are used to cope with agregate risks. It seem that, in that case, index-based insurance is a complement as well as a subsititute to informal insurance. We will thus try to investigate how supplying formal risk pooling tool could harm informal networks.

However, poor households are shown to be less able to use such informal networks (Thomas et al., 2011) and remain less able to increase their average outcome by adopting new technologies that often lead to implementing riskier production strategies. Moreover, informal insurance is incomplete, leading to a lower average income as a consequence of ex ante risk-mitigating behaviours (Rosenzweig and Binswanger, 1993 and Barett and Carter, 2006) at high costs (as reviewed by Hill, 2011).

Risk management

Insurance could also replace other previous strategies of self-insurance: build-up savings, livestock but also by diversifying incomes (crop or activities diversification) or risks (intercropping, fragmentation of fields, to grow a mix of crops that embody differing levels of susceptibility to climatic shocks, delaying planting until rainfall patterns are more certain). These ex ante actions often come at high cost: Bliss and Stern (1982) showed that a two-week delay in planting following the onset of seasonal rains is associated with a 20 percent reduction in rice yields. Consumption-smoothing strategies including the use of savings and borrowing, transfers within networks to spread risk, and accumulation and decumulation of physical assets are other examples of risk management.

Risk coping

Farmers are encouraged to pool the risks ex post, *i.e.* after its realization, by smoothing consumption over time (such as storing, saving and borrowing) or across households (risk pooling) but also by migrating temporarily or adjusting stocks such as mortgage of personal goods as anecdotically described in Collin et al. (2009). Providing formal insurance could have a negative impact on informal risk coping networks, as noted by Alderman and Haque (2007). Transfers from migrants, neighbours, family or friends are well described in Fafchamps (2007), and their relation to risk transfert products has recently been analyzed by Barnett et al. (2008).

Empirical evidence of low informal pooling

Empirical studies point out the very low use of livestock as a buffer stock (Fafchamps et al., 1998; Lybbert et al., 2004; Lentz and Barrett, 2004 and Unruh, 2008). Farmers smooth consumption by adjusting stocks of stored grain, which is also very costly, depending on material, weather and crops. For instance stored grain undergoes very high depreciation rates associated with different degradation sources, such as moisture, rodents and insects.

Kazianga and Udry (2006) only found evidence of a very low risk sharing among households facing climatic shocks in Burkina Faso. Pan (2009) found evidence that transfers have a minor impact on risk pooling. A potential explanation is that having recourse to informal credit could also be very costly (Collins et al., 2009).

Finally it could be argued that the cost of informal practices limit their attractiveness, especially compared to formal insurance products. Dercon et al. (2008) reviewed the studies which evaluate these costs, highlighting the need for health and crop micro-insurances. However, their potential substitution by insurance and informal risk mitigation methods could lower their take up, especially when information about their relative costs is not easily available.

2.4.2 Credit

It seem that the complementarity with input credit could play a great role in increasing the potential of insurance interest: by lowering the default rate and then the price as put forward by Dercon and Christiaensen (2011); by crowding-in input supply and demand as in Carter et al. (2009) and Carter et al. (2011), input use (Hill and Viceisza, 2009) and technology adoption.

Mineral fertilizers are costly and their supply is quite limited (in quantity and in quality) in West Africa. Assuming that the inexistence of competitive loan markets is partly due to risk issues, the combination of WII with input credits presents a double interest. First, it allows the use of the distribution networks of micro-finance institutions. Second, it mitigates the default risk for lenders, and ceteris paribus lowers the credit interest rate. Lowering the default rate reduces the potential adverse selection induced by loans supplied for a given interest rate.

One could think that providing WII bundled with other more attractive products, such as fertilizer credit, could increase take up and be a possible justification of joining intensification loans. However, as already discussed above, Giné and Yang (2009) showed evidence of a very low take up rate even in such scheme. This study is a randomized control experiment ran in Malawi, where WII was supplied to farmers jointly with an input loan for high-yielding hybrid maize and groundnut seeds. Insurance supply did not increase the loan take up rate and may even possibly lower it contrarily to what is found in Peru in Carter et al. (2007). Another potential, and already mentionned, explanation is the very low collateral coupled with a high default rate of farmers that undertake the loans in Malawi.

2.4.3 Seasonal forecasts

Weather forecasts being necessarly imperfect, they create a room for insurance products, by increasing the risk taken by farmers in the case of a bad forecast. In this context insurance product seem to be a rather good complement at first sight: Carriquiry and Osgood (2011) shows the potential synergies between both products in a theoretical framework. However including weather forecasts in an insurance model also induces information problems, stemming from differential information between the principal (insurer) and the agents (farmers) that could create adverse selection issues. Insurer should fix a closing date and be aware of all forecasts available to farmers to bound this ex post adverse selection. Experience from East Africa tend to show that herders seem to update their belief when external forecasts are about below normal rainfall but do not when above normal rainfalls are forecasted (Lybbert et al., 2011). Jewson and Caballero (2003) proposed two major methods, using different kinds of forecasts, for the pricing of weather derivatives.

Forecasts also allow growers to make a more accurate trade-off between different cultivars, for instance between improved (genetic selection or manipulation) and traditional ones. Certain well evolved crops, with short physiological cycles are more costly than traditional ones. Being more resistant to drought periods, they are more productive in average for the farmer that takes the risk to buy it. They also make robust weather forecasts very attractive as showed by Roudier et al. (2012) in the case of millet in Niger. Climatic forecasts are a mean to improve farm risk management and crop choices, increasing risk taking[13].

Weather forecasting can be implemented in the very short run or on longer periods as such as seasonal forecasting that generally predict the type of the rainy season about three month before its beginning. There are two major type of worthwhile seasonal weather forecasts in western Africa, the first concerns the date of onset of the rainy season (see next section below), the second the cumulative rainfall during crop cycle (cf. IRI, Agrhymet and Ensemble previsions integrated into the Pressao programme in West Africa).

Globally, the El Niño Southern Oscillation (ENSO defining El Niño/La Nina years) phenomenon, originally observed by Peruvian farmers, is often cited as an interesting way of improving WII products (e.g. for East Africa Osgood et al., 2007) by inciting the intensification of production during forecasted good rainy seasons. Carriquiry and Osgood (2011) evoque the need for an interlocking frame of insurance and reinsurance for allowing insurance premium to adapt each year to the ENSO weather foresccasts.

The case of the onset of the rainy season

Late onset of the rainy season decreases its length and thus the probable total rainfall that will be used by crops. It is especially the case for monsoon climates, such as the ones in part of sub-saharan Africa and India, comon in the tropics. Sowing too early due to a false start of the rainy season could indeed be costly since resowing is associated with significant labor and sometimes seed costs. The major role of the onset of the rainy season in western Africa explains the particular attention given to this type of forecast in the literature (e.g. Marteau et al, 2011).

Rozenzweig and Binswanger (1993) already found that the delay of the monsoon in semi-arid India can have considerable negative effects on agricultural yields and profit. If the onset moves back from one standard deviation the profit would experience a 35 percent reduction for farmers with wealth holdings below the 25^{th} percentile,. Giné et al. (2009) emphasize the issue of planting decision, and its impact on yield. They estimate the cost of a bad forecast to about 8 or 9% of the harvest higher probability of replanting.

[13] See Meza et al. (2008) for a literature review about forecasts valuation.

2.4.4 International food prices insurance

WIIs are not protecting against covariate risks such as international prices variations that are crucial in the case of cash crops. Rainfall data indeed often reflect on detrended price time-series of a food crop produced locally, generally with a one year lag. Molini et al. (2010) studied a non-parametric safety net protecting against rainfall and international price shocks within the Ghanaian context.

The literature on the topic only considers cash crop price insurance (i.e. Hill, 2010 or Karlan et al., 2011) because food crops prices have an undefined impact on poor household depending on the consumption and harvest i.e. if they are net buyers or sellers (in the chapter II discussing the case of millet growers in Niger is a good example of such situation). One could however argue that a safety net could be designed in order to protect against both type of shocks, simply reducing variance of the price.

The comparison of weather vs. price risk is the object of the third chapter of this essay, applied to the cotton sector in Cameroon.

2.5 Supply side issues

2.5.1 Robustness to climate change

Due to global warming, there is an upward trend in local temperatures in almost every region. If the index of an WII includes temperatures but does not account for this trend, the calculation of the expected indemnity is biased. The continuation of an upward trend in temperature is very likely over the next decades, but the magnitude of this trend is highly uncertain. First, according to the last IPCC (2007) synthesis report, global warming in 2100 could be between 1.4 °C and 5.8 °C, depending both on climate sensitivity and on greenhouse gas emissions. Second, uncertainty on local warming could be even higher than that on global warming.

In some regions (e.g. West Africa) rainfall data also exhibit trends, which may be due to global warming, natural climate variability and/or changes in land use. The difficulty is higher than for temperature since in many regions, such as West Africa again, climate models disagree on whether global warming will entail an increase or a decrease in rainfall. Not only the average, but also the inter-annual variability of the rainfall level may change due to global warming. Moreover, the evolution in average rainfall or temperature augur major change in extreme events. For example, it is shown in Siebert and Ward (2011) that a 10% change in the mean rainfall can lead to a change of order times 2 in the number of threshold-crossing low seasonal rainfall totals, even without invoking any change in the characteristics of the interannual variability.

Trends formulation in designing WIIs and are becoming overriding issues (Collier et al., 2009) because the increasing impact and variability of weather-related losses are clearly visible in the long run (Mills, 2005). Simple detrending methods based on past data are routinely used in WII design (Jewson and Penzer, 2005). However, they cannot correctly account for complex non-stationarities, like the succession of humid and dry decades in the Sahel (Dai et al., 2004). Nor can they deal with the above-mentioned uncertainty with regard to future local climates. Hence, the presence of a trend in the data used to build the index can lead to private suppliers turning away from local markets. This was the case in Morocco (Skees et al., 2001) in spite of the twenty years of precipitation data and the provision promises made by the government.

Then, the duration of the service provision is dependent upon the long run solvability of the insurer and thus its ability to compensate for increasing risks. This point is even more crucial for insuring and re-insuring extreme events as such as catastrophe insurances (cat bonds or other weather derivatives) or for regions that are particularly hit by climate change. Hochrainer et al. (2007) tested the robustness of a WII in Malawi using climate forecasts generated by the MM5 and PRECIS regional climate models. They questioned its long run sustainability until 2080.

Finally it seems that renegociation of the contract to is the only way to get rid of trend issues. It is however associated with high transaction costs, a significant increase in contract complexity and related ambiguity for buyers. Such potential modification issues were also found during the Mexican experience, the threshold were not subjected to any modifications despite the substantial amount of research on drought resistant crop undertaken while the program was running, according to Fuchs and Wolff (2011a).

Yield distributions is approximated by normal distribution, or distribution bounded at zero (such as the lognormal, Beta or Weibull distributions as in De Bock et al., 2010), however the joint distribution of yield and weather is scarce in the literature, except for a recent contribution of Woodward (2011) who inquires Weibull distribution of yields conditional on weather events. Bokusheva (2011) studies the dependence in yield and weather joint distributions and shows that the relationship between weather and crop yields is not fixed and can change over time. Using regression analysis and copula approach, she reveals statistically significant temporal changes that put into question current methodology of the WII design.

2.5.2 Spatial variability of climate and the scaling of insurances

Covariate vs. idiosyncratic shocks

There exists different sources of risk: price fluctuations (covariant, at least when markets are integrated), climatic shocks (intermediate risk) and individual shocks (totally idiosyncratic). Covariant shock can only be assumed by a formal insurer that could use risk layering to pool highly (spatially) correlated risks as long as informal insurance is playing the role of smoothing indiosyncratic consumption shocks at a lower geographical scale. Weather insurance would in this case only be used for intermadiary risks (Mahul and Skees, 2007).

Optimal spatial scale

Risk covariance is a major source of insurance market failure in low income countries and explains the high subsidization rate of agricultural insurances (Barnett et al., 2008).

Spatial risk correlation is a major impediment of WII implementation. It increases income variance for the insurer, hence the insurance premium. The only ways to lower the variance of income for a given spatial variability of shocks are to insure a larger area, allowing a better pooling, and/or to transfer a part of the risk to an international insurer or reinsurer through risk layering. For instance, reinsurance was needed for drought insurance in Ethiopia. In this Ethiopian context, Meze-Hausken et al. (2009) studied insurance provision on 30 years and 15 stations with an HDA and conclude that pooling over the country limits the need for capital requirement.

Spatial variability reduces this problem but increases what we called spatial basis risk at the end of section 3.1.3.2., for a given weather station density. There is thus a trade off between the cost of meteorological station installation and the level of the basis risk.

In practice the maximum distance to the nearest weather station is set at between 20 (in Senegal) and 30 km (in Malawi, in most cases in India and in Canada according to Hartell et al., 2006). Insurers indeed often use the 20km rule, meaning that the rain gauge or weather observation should not be situated at more than 20km from the individual agricultural plot.

However there are many arguments contradicting this rule. For instance, in some regions the spatial variability of weather is significant even at 10 km or less. Gommes (2012) shows that in Ethiopia, depending on the period and the region considered, the distance between neighbouring stations and the one considered should be reduced to between 0 and 0.77 km in order to account for 90% of the variance of rainfall estimates. It is also probable that horizontal and vertical gradient magnitude are different under many climates (Greatex, 2012). This calls for increasing the density of rain gauges, which would however substantially raise WII management costs (installation, operation and maintenance).

In most WIIs, only the closest weather station ('closest station' rule) is taken into account to calculate the indemnity. However, interpolation methods can also be used to infer the meteorological index realization over a geo-referenced grid (Paulson and Hart, 2006). Method complexity differs from simple and determinist ones: simple linear weighting, decreasing with distance of stations around or squared weighting like the Inverse Distance Weighted Averaging (IDWA), to stochastic ones: Kriging based on Gaussian multivariate statistical distributions.

2.5.3 Institutional aspects

There are also many institutional barriers restraining WII implementation. In particular it is crucial that the country institutional framework and regulatory environment be adapted to private insurers, e.g. allowing contract enforcement at low cost (Carpenter and Skees, 2005 and Henderson, 2002). South Africa, India (Indian Insurance Regulatory and Development Authority, IRDA), Peru and the Philippines (Insurance Commission of the Philippines: Insurance Code of 1974) adapted their respective legislation to facilitate private micro-insurance initiatives (Wiedmaier-Pfister and Chatterjee, 2006). However, a total lack of contract law enforcement in Malawi - where contract farming is not particularly defined from a juridical point of view - did not prevent WII implementation. On the other hand, in West Africa index-based insurance was not allowed for a long time by the regulation authority[14] and local insurance companies are often not used to work with the agricultural sector.

Finally, a very important detail we did not mention is the securization of the meteorologcial station network, that simply could be covered by a simple sleave in order to increase the probability of indemnification...

3 Conclusion

The research agenda about insuring developing countries' households against climatic risk is about improving five principal points:

- weather index design depending on the availability of underlying data and weather forecasts, including trends apprehension and downscaling methods.
- optimal geographical zone of WIIs and the relation with rain gauges network density.
- quantification of the gains for farmers, by estimating their risk aversion and the extent of modifications in cultivation practices.
- acuity of cultural and institutional matters in risk pooling products, that largely depends on field specificities, requiring close cooperation with local stakeholders.

We can ask ourselves whether such products are adapted to agent showing high risk and/or ambiguity aversion or to agents who may have intensive and creditworthy productions and thus could invest in costly inputs. Second, risk diversification being very low for poor farmers, their incentive to buy such products regarding their low solvency, could be substantially limited by a relatively high proportion of non-rain-related losses. Third, one has to recall that implementation issues of such programs still depends on its

[14]Western African countries have a two stage regulatory system for insurance: a Regional Regulator based in Gabon, responsible for regulating the insurance market for over 14 countries of West and Central Africa and the National Divisions of Insurance. At the regional level, insurance is entirely regulated by CIMA (Conférence Inter-africaine sur le Marché des Assurances) that is in charge of approving any new insurance company and insurance product in its member states. CIMA has representatives in each Member State. They are normally hosted in the Ministry of Finance or of Treasury. The National Division is in charge of pre-approving any insurance product and new licenses. The CIMA Code dedicates an entire chapter to Agricultural Risks (Livre I/Titre II/Chapitre IV).

acceptability on the field that seems to be driven by psychological and educational factors facilitated by field study and communication programs.

Finally, a large set of possibilities emerged in the recent developement of such products in the design (index choice, indemnification rate, geographical cover and zoning, subsidization level), the implementation (institutional arrangement: supplying level[15] and distribution channels, bundled with input credit, mandatory or not) and the diversity of products. Those possibilities should be considered before implementing a WII scheme. It goes by considering the goals of the product in deeper terms. Establishing a safety net, offering subsidized insurance to help farmers escaping a poverty trap situation is very different from elaborating a programme protecting against catastrophic events, such as heavy droughts, occuring every 25 years.

References

Akay, A., P. Martinsson, H. Medhin, and S. T. Trautmann (2009): "Attitudes toward Uncertainty among the Poor: Evidence from Rural Ethiopia," IZA Discussion Papers 4225, Institute for the Study of Labor (IZA).

Akponikpe, P. B. I. (2008): "Millet Response to Water and Soil Fertility Management in the Sahelian Niger : Experiments and Modeling," Ph.D. thesis, Univ. Catholique de Louvain, Thèse Doc. Soil physics, Hydraulics, Water management and Modeling.

Alary, D., C. Gollier, and N. treich (2010): "The effect of ambiguity aversion on insurance demand," Discussion paper, IDEI, Toulouse.

Alderman, H., and T. Haque (2006): "Countercyclical Safety Nets for the Poor and Vulnerable," *Food Policy*, 31, 372–383.

Alderman, H., C. H. Paxson, and DEC (1992): "Do the poor insure? A synthesis of the literature on risk and consumption in developing countries," Policy Research Working Paper Series 1008, The World Bank.

Allais, M. (1953): "Le Comportement de l'Homme Rationnel devant le Risque: Critique des Postulats et Axiomes de l'Ecole Americaine," *Econometrica*, 21(4), 503–546.

Allen, R. G., L. S. Pereira, D. Raes, and M. Smith (1998): *Crop evapotranspiration - Guidelines for computing crop water requirements*, vol. 56 of *FAO Irrigation and Drainage*. FAO, Rome.

[15] Insuring producers' organization may be more easy, decreasing the fixed costs, entity with legal authority to contract with banks, easier than with smallholder farmers, thay can use their extensive relationship with primary cooperatives and farmers to serve as enforcers of the loan/insurance contracts, minimizing default risk. Ex: Malawi, EPIICA project in Ethiopia.

Alpizar, F., F. Carlsson, and M. Naranjo (2009): "The effect of risk, ambiguity, and coordination on farmers adaptation to climate change: A framed field experiment," Working Papers in Economics 382, Gteborg University, Department of Economics.

Arnott, R., and J. Stiglitz (1991): "Moral Hazard and Nonmarket Institutions: Dysfonctional Crowding out or Peer Monitoring?," *American Economic Review*, 81, 179–190.

Arun, T., and M. Bendig (2010): "Risk management among the poor: The case of microfinancial services," IZA Discussion Papers.

Bardsley, P. (1986): "A Note On The Viability Of Rainfall Insurance - Reply," *Australian Journal of Agricultural Economics*, 30(01).

Bardsley, P., A. Abey, and S. V. Davenport (1984): "The Economics of Insuring Crops Against Drought," *Australian Journal of Agricultural Economics*, 28(01).

Barham, B. L., J.-P. Chavas, D. Fitz, V. Rios Salas, and L. Schechter (2011): "The Roles of Risk and Ambiguity in Technology Adoption," *SSRN eLibrary*.

Barnett, B. J., C. B. Barrett, and J. R. Skees (2008): "Poverty Traps and Index-Based Risk Transfer Products," *World Development*, 36(10), 1766–1785.

Barrett, C., M. Carter, and P. Little (2006): "Understanding and reducing persistent poverty in Africa: Introduction to a special issue," *The Journal of Development Studies*, 42(2), 167–177.

Behrman, J. R. (1989): "Book Review: Crop Insurance for Agricultural Development: Issues and Experience," *Indian Economic Review*, 24(2), 277–280.

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, 71–84.

Bhattamishra, R., and C. B. Barrett (2010): "Community-Based Risk Management Arrangements: A Review," *World Development*, 38(7), 923–932.

Bliss, C. J., and N. H. Stern (1982): *Palanpur: The Economy of an Indian Village*, no. 9780198284192 in OUP Catalogue. Oxford University Press.

Bloch, F., G. Genicot, and R. Debraj (2008): "Informal Insurance in Social Networks," *Journal of Economic Theory*, 143, 36–58.

Bokusheva, R. (2011): "Measuring dependence in joint distributions of yield and weather variables," *Agricultural Finance Review*, 71(1), 120141.

Boucher, S. R., M. R. Carter, and C. Guirkinger (2008): "Risk Rationing and Wealth Effects in Credit Markets: Theory and Implications for Agricultural Development," *American Journal of Agricultural Economics*, 90(2), 409–423.

Bryan, G. (2010): "Ambiguity and Insurance," Yale University Department of Economics, mimeo.

Byun, H. R., and D. A. Wilhite (1999): "Objective Quantification of Drought Severity and Duration," *Journal of Climate*, 12(9), 2747–2756.

Cai, H., Y. Chen, H. Fang, and L.-A. Zhou (2009): "Microinsurance, Trust and Economic Development: Evidence from a Randomized Natural Field Experiment," Working Paper 15396, National Bureau of Economic Research.

Cameron, L., and M. Shah (2011): "Risk-Taking Behavior in the Wake of Natural Disasters," Discussion paper, University of California-Irvine.

Carriquiry, M. A., and D. E. Osgood (2012): "Index Insurance, Probabilistic Climate Forecasts, and Production," *Journal of Risk and Insurance*.

Carter, M., L. Cheng, and A. Sarris (2011): "The impact of interlinked index insurance and credit contracts on financial market deepening and small farm productivity," Mimeo.

Carter, M., F. Galarza, and S. Boucher (2007): "Underwriting area-based yield insurance to crowd-in credit supply and demand," *Savings and Development*, (3).

Chantarat, S., C. G. Turvey, A. G. Mude, and C. B. Barrett (2008): "Improving humanitarian response to slow-onset disasters using famine-indexed weather derivatives," *Agricultural Finance Review*, 68(1), 169–195.

Chetaille, A., D. Lagandré, A. Duffau, G. Horréard, B. Oggeri, and I. Rozenkopf (2010): "Gestion de risques agricoles par les petits producteurs, focus sur l'assurance-récolte indicielle et le warrantage," Discussion paper, GRET.

Clarke, D., and G. Kalani (2011): "Microinsurance decisions: evidence from ethiopia," Mimeo.

Cole, S. A., X. Giné, J. B. Tobacman, P. B. Topalova, R. M. Townsend, and J. I. Vickery (2011): "Barriers to Household Risk Management: Evidence from India," *SSRN eLibrary*.

Collier, B., J. Skees, and B. Barnett (2009): "Weather Index Insurance and Climate Change: Opportunities and Challenges in Lower Income Countries," *The Geneva Papers on Risk and Insurance - Issues and Practice*, 34(3), 401–424.

Collins, D., J. Morduch, S. Rutherford, and O. Ruthven (2009): *Portfolios of the Poor: How the World's Poor Live on $2 a Day*. Princeton University Press.

Conley, T. G., and C. R. Udry (2010): "Learning about a New Technology: Pineapple in Ghana," *American Economic Review*, 100(1), 35–69.

Dandekar, V. (1977): "Crop insurance for developing countries," Discussion paper, Agricultural Development Council, New York, No. 10.

De Bock, O. (2010): "Etude de faisabilité : Quels mécanismes de micro-assurance privilégier pour les producteurs de coton au Mali ?," Discussion paper, CRED, PlaNet Guarantee.

De Bock, O., and W. Gelade (2012): "The Demand for Micro-Insurance: A Literature Review," FUNDP, Mimeo.

de Finetti, B. (1974): *Theory of Probability*, vol. 1. John Wiley and Sons, New York.

de Janvry, A., M. Burke, and J. Quintero (2011): "Providing indexbased agricultural insurance to smallholders: Recent progress and future promise," in *ABCDE Conference*, Paris. AFD.

Deaton, A. (1990): "On Risk, Insurance, and Intra-Village Consumption Smoothing," Mimeo.

Delavande, A., X. Giné, and D. McKenzie (2011): "Measuring subjective expectations in developing countries: A critical review and new evidence," *Journal of Development Economics*, 94(2), 151–163.

Delpierre, M. (2009): "Farm Input Use in a Context of Liquidity Constraints and Contract Unenforceability," *Journal of African Economies*, 18(3), 496–528.

Denicola, F. (2011): "The impact of weather insurance on consumption, investment, and welfare," Discussion paper, mimeo.

Dercon, S. (2004): "Growth and Shocks: evidence from rural Ethiopia," Development and Comp Systems 0409036, EconWPA.

Diaz Nieto, J., S. Cook, M. Lundy, M. Fisher, D. Sanchez, and E. Guevarra (2005): "A System of Drought Insurance for Poverty Alleviation in Rural Areas," Discussion paper, BMZ, GTZ, CRS.

Duflo, E., M. Kremer, and J. Robinson (2008): "How High Are Rates of Return to Fertilizer? Evidence from Field Experiments in Kenya," *American Economic Review*, 98(2), 482–88.

——— (2009): "Nudging Farmers to Use Fertilizer: Theory and Experimental Evidence from Kenya," NBER Working Papers 15131, National Bureau of Economic Research, Inc.

Elbersa, C., J. W. Gunning, and L. Pan (2007): "Insurance and Rural Welfare: What Can Panel Data Tell Us?," CSAE Working Paper Series 2007-13, Centre for the Study of African Economies, University of Oxford.

Ellsberg, D. (1961): "Risk, Ambiguity, and the Savage Axioms," 75(4), 643–669.

Engle-Warnick, J., J. Escobal, and S. Laszlo (2007a): "Ambiguity Aversion as a Predictor of Technology Choice: Experimental Evidence from Peru," CIRANO Working Papers 2007s-01, CIRANO.

——— (2007b): "Ambiguity Aversion as a Predictor of Technology Choice: Experimental Evidence from Peru," CIRANO Working Papers 2007s-01, CIRANO.

Eswaran, M., and A. Kotwal (1990): "Implications of Credit Constraints for Risk Behaviour in Less Developed Economies," *Oxford Economic Papers*, 42(2), 473–82.

Fafchamps, M. (2003): *Rural poverty, risk and development*. E. Elgar, Cheltenham, U.K., Includes bibliographical references (p. 227-255) and index. Accessed from http://nla.gov.au/nla.cat-vn3069448.

Fafchamps, M. (2007): "Risk Sharing and Network Formation," *American Economic Review Papers and Proceedings*, 97(2).

Fafchamps, M. (2010): "Vulnerability, Risk Management, and Agricultural Development," *African Journal of Agricultural Economics*, 5.

Fafchamps, M., and S. Lund (2003): "Risk-sharing Networks in Rural Philippines," *Journal of Development Economics*, 71, 261–287.

Fafchamps, M., C. Udry, and K. Czukas (1998): "Drought and saving in West Africa: are livestock a buffer stock?," *Journal of Development Economics*, 55, 273–305, [1] doi:10.1016/S0304-3878(98)00037-6.

Fuchs, A., and H. Wolff (2011a): "Concept and unintended consequences of Weather Index Insurance: the Case of Mexico," *American Journal of Agricultural Economics*, 93(2), 505–511.

——— (2011b): "Concept and Unintended Consequences of Weather Index Insurance: The Case of Mexico," *American Journal of Agricultural Economics*, 93(2), 505–511.

——— (2011c): "Drought and Retribution: Evidence from a large scale Rainfall-Indexed Insurance Program in Mexico," Discussion paper, Berkeley.

Galarza, F. B., and M. R. Carter (2010): "Risk Preferences and Demand for Insurance in Peru: A Field Experiment," 2010 Annual Meeting, July 25-27, 2010, Denver, Colorado 61871, Agricultural and Applied Economics Association.

Gaurav, S., S. Cole, , and J. Tobacman (2011): "A Randomized Evaluation of the impactT of Financial Literacy on Rainfall insurance Take up in Gujarat," Discussion paper.

Gheyssens, J., and I. Gnther (2011): "Risk experiments in gains and losses: Do rural villagers want micro-insurance?," Discussion paper, ETH.

Giné, X., M. Lev, R. M. Townsend, and J. I. Vickery (2010): "Microinsurance: A Case Study of the Indian Rainfall Index Insurance Market," *SSRN eLibrary*.

Giné, X., M. R. Townsend, and J. I. Vickery (2009): "Forecasting when it matters: evidence from semi-arid India," Discussion paper, World Bank.

Giné, X., R. Townsend, and J. Vickery (2008): "Patterns of Rainfall Insurance Participation in Rural India," *World Bank Econ Rev*, 22(3), 539–566.

Giné, X., and D. Yang (2009): "Insurance, credit, and technology adoption: Field experimental evidence from Malawi," *Journal of Development Economics*, 89, 1–11, 0304-3878.

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

Gollier, C. (2011): "Does ambiguity aversion reinforce risk aversion? Applications to portfolio choices and asset prices," .

Gommes, R. (2012): "Beyond simple, one station indices," in *JRC/IRI Workshop on The challenges of index-based insurance for food security in developing countries*, Ispra. JRC, ftp://mars.jrc.ec.europa.eu/index-insurance-meeting/presentations/4_gommes.pdf.

Greatrex, H. (2012): "The spatial variability from raingauge to sattelites," Ispra. JRC, ftp://mars.jrc.ec.europa.eu/index-insurance-meeting/presentations/4_gommes.pdf.

Halcrow, H. G. (1948): "The theory of crop insurance," Ph.D. thesis, Univ. of Chicago, Ph.D. diss. in Economics.

Harrison, G. (2011): "Experimental methods and the welfare evalution of policy lotteries," *European Review of Agricultural Economics*, 38(3), 335–360.

Hartell, J., H. Ibarra, J. Skee, and J. Syroka (2006): "Risk Management in Agriculture for Natural Hasards," Discussion paper, ISMEA.

Hazell, P., J. Anderson, N. Balzer, A. H. Clemmensen, U. Hess, and F. Rispoli (2010a): “Potential for scale and sustainability in weather index insurance for agriculture and rural livelihoods,” Discussion paper, International Fund for Agricultural Development and World Food Programme (IFAD), Rome.

——— (2010b): “Potential for scale and sustainability in weather index insurance for agriculture and rural livelihoods,” Discussion paper, International Fund for Agricultural Development and World Food Programme (IFAD), Rome.

Hellmuth, M., D. Osgood, U. Hess, A. Moorhead, and H. Bhojwani (2009): “Index insurance and climate risk: prospects for development and disaster management,” Discussion paper, International Research Institute for Climate and Society (IRI), Climate and Society No. 2.

Henderson, R. (2002): *Weather Risk Management: Markets, Products and Applications: Legal and Regulatory Issues*. Palgrave Macmilan.

Hess, U., and J. Syroka (2005): “Weather-Based Insurance in Southern Africa: The Case of Malawi,” Discussion paper, The World Bank, Washington DC.

Hill, R. V., J. Hoddinott, and N. Kumar (2011): “Adoption of Weather Index Insurance Learning from Willingness to Pay among a Panel of Households in Rural Ethiopia,” Discussion paper, IFPRI, 01088.

Hill, R. V., and M. Robles (2011): “Flexible insurance for heterogeneous farmers: Results from a small-scale pilot in Ethiopia,” IFPRI discussion papers 1092, International Food Policy Research Institute (IFPRI).

Hochrainer, S., R. Mechler, G. Pflug, and A. Lotsch (2008): “Investigating the Impact of Climate Change on the Robustness of Index-Based Microinsurance in Malawi,” *SSRN eLibrary*.

Hoddinott, J. (2006): “Shocks and their consequences across and within households in Rural Zimbabwe,” *The Journal of Development Studies*, 42(2), 301–321.

Jalan, J., and M. Ravallion (2005): *Household Income Dynamics in Rural China*. in Stefan Dercon (ed.), Insurance against Poverty, Oxford: Oxford University Press.

Jewson, S. (2004): “Comparing the Potential Accuracy of Burn and Index Modelling for Weather Option Valuation,” *SSRN eLibrary*.

Jewson, S., and R. Caballero (2003): “The Use of Weather Forecasts in the Pricing of Weather Derivatives,” *Meteorological Applications*, 10, 377–389.

Kahneman, D., and A. Tversky (1979): “Prospect Theory: An Analysis of Decision under Risk,” *Econometrica*, 47(2), 263–91.

Kapphan, I. (2011): "Weather Risk Management in Light of Climate Change Using Financial Derivatives," Ph.D. thesis, ETH, Zurich, Economics.

Karlan, D., R. Osei, I. Osei-Akoto, and C. Udry (2012): "Agricultural Decisions after Relaxing Credit and Risk Constraints," Discussion paper, Jpal (MIT), IPA.

Karlan, D. S., E. Kutsoati, M. McMillan, and C. R. Udry (2011): "Crop Price Indemnified Loans for Farmers: A Pilot Experiment in Rural Ghana," *Journal of Risk and Insurance, Vol. 78, No. 1, pp. 37-55, 2011.*

Kazianga, H., and C. Udry (2006): "Consumption smoothing? Livestock, insurance and drought in rural Burkina Faso," *Journal of Development Economics*, 79(2), 413–446, 0304-3878 doi: DOI: 10.1016/j.jdeveco.2006.01.011.

Kellner, U., and O. Musshoff (2011): "Precipitation or water capacity indices? An analysis of the benefits of alternative underlyings for index insurance," *Agricultural Systems*, 104(8), 645 – 653.

Keynes, J. M. (1921): *A treatise on probability*. Harper & Row.

Khan, J. (2011): "Impact of educational intervention on knowledge, attitude and willingness-to-pay for health insurance using occupational solidarity and an exploration of relevant actors' views - a study of informal sector workers in urban bangladesh," Discussion paper, Mimeo.

Knight, F. H. (1921): "Risk, Uncertainty and Profit," *University of Illinois at Urbana-Champaign's Academy for Entrepreneurial Leadership Historical Research Reference in Entrepreneurship.*

Lasse, B., X. Giné, J. Goldberg, and D. Yang (2010): "Commitments to Save: A Field Experiment in Rural Malawi," Discussion paper, Michigan University.

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

Liu, E. M. (2008): "Time to Change What to Sow: Risk Preferences and Technology Adoption Decisions of Cotton Farmers in China," Working Papers 1064, Princeton University, Department of Economics, Industrial Relations Section.

Liu, H.-H., and A. M. Colman (2009): "Ambiguity aversion in the long run: Repeated decisions under risk and uncertainty," *Journal of Economic Psychology*, 30(3), 277 – 284.

Lybbert, T. J., and C. B. Barrett (2007): "Risk Responses to Dynamic Asset Thresholds," *Review of Agricultural Economics*, 29(3), 412–418.

Lybbert, T. J., C. B. Barrett, J. G. McPeak, and W. K. Luseno (2007): "Bayesian Herders: Updating of Rainfall Beliefs in Response to External Forecasts," *World Development*, 35(3), 480–497.

Lybbert, T. J., Christopher, B. Barrett, S. Desta, and D. L. Coppock (2004): "Stochastic Wealth Dynamics and Risk Management Among a Poor Population," *The Economic Journal*, 114(498), 750–777, 10.1111/j.1468-0297.2004.00242.x.

Maccini, S., and D. Yang (2009): "Under the Weather: Health, Schooling, and Economic Consequences of Early-Life Rainfall," *American Economic Review*, 99(3), 1006–26.

Macours, K. (2012): "Volatility, Risk and Household Poverty: Micro-evidence from Randomized Control Trials," 2012 Conference, August 18-24, 2012, Foz do Iguacu, Brazil 128293, International Association of Agricultural Economists.

Mahul, O., and J. Skees (2007): "Managing agricultural risk at the country level : the case of index-based livestock insurance in Mongolia," Policy Research Working Paper Series 4325, The World Bank.

Mahul, O., and C. J. Stutley (2010): "Government Support to Agricultural Insurance: Challenges and Options for Developing Countries," Discussion paper, The World Bank, Washington DC.

Mahul, O., A. Touré, W. Dick, and B. Muller (2009): "Index-Based Crop Insurance in Senegal Promoting Access to Agricultural Insurance for Small Farmers," Discussion paper, The World Bank.

Malchow-Moeller, N., and B. J. Thorsen (2000): "A Dynamic Agricultural Household Model with Uncertain Income and Irreversible and Indivisible Investments under Credit Constraints," Economics Working Papers 2000-7, School of Economics and Management, University of Aarhus.

Marteau, R., B. Sultan, V. Moron, and A. Alhassane (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.

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.

Meza, F. J., J. W. Hansen, and D. Osgood (2008): "Economic Value of Seasonal Climate Forecasts for Agriculture: Review of Ex-Ante Assessments and Recommendations for Future Research," *Journal of Applied Meteorology and Climatology*, 47, 1269–+.

MEZE-HAUSKEN, E., A. PATT, AND S. FRITZ (2009): "Reducing climate risk for micro-insurance providers in Africa: A case study of Ethiopia," *Global Environmental Change*, 19(1), 66 – 73.

MILLS, E. (2005): "Insurance in a Climate of Change," *Science*, 309(5737), 1040–1044.

MIRANDA, M. J., AND J. W. GLAUBE (1997): "Systemic Risk, Reinsurance, and the Failure of Crop Insurance Markets," *American Journal of Agricultural Economics*, 79(1), 206–215.

MOBARAK, A. M., AND M. ROSENZWEIG (2012): "Selling Formal Insurance to the Informally Insured," Discussion paper, Yale University.

MOLINI, V., M. KEYZER, B. V. D. BOOM, W. ZANT, AND N. NSOWAH-NUAMAH (2010): "Safety Nets and Index-Based Insurance: Historical Assessment and Semiparametric Simulation for Northern Ghana," *Economic Development and Cultural Change*, 58(4), pp. 671–712.

——— (2010): "Safety Nets and Index-Based Insurance: Historical Assessment and Semiparametric Simulation for Northern Ghana," *Economic Development and Cultural Change*, 58(4), 671–712.

MUDE, A. G., S. CHANTARAT, C. B. BARRETT, M. R.CARTER, M. IKEGAMI, AND J. G. MCPEAK (2010): "Insuring Against Drought-Related Livestock Mortality: Piloting Index Based Livestock Insurance in Northern Kenya," *SSRN eLibrary*.

MULLALLY, C. (2011): "Perceptions and Participation: Randomized Encouragement Designs and Demand for Index Insurance," Discussion paper, UC Davis Agecon, mimeo.

NORTON, M., E. HOLTHAUS, M. MADAJEWICZ, D. OSGOOD, N. PETERSON, M. GEBREMICHAEL, C. MULLALLY, AND T. TEH (2011a): "Investigating demand for weather index insurance: Experimental evidence from ethiopia," in *2011 Annual Meeting, July 24-26, 2011, Pittsburgh, Pennsylvania, Agricultural and Applied Economics Association*.

NORTON, M., E. HOLTHAUS, M. MADAJEWICZ, D. E. OSGOOD, N. PETERSON, M. GEBREMICHAEL, C. MULLALLY, AND T. TEH (2011b): "Investigating Demand for Weather Index Insurance: Experimental Evidence from Ethiopia," 2011 Annual Meeting, July 24-26, 2011, Pittsburgh, Pennsylvania 104022, Agricultural and Applied Economics Association.

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.

Osgood, D., M. McLaurin, M. Carriquiry, A. Mishra, F. Fionnella, J. Hansen, N. Peterson, , and N. Ward (2007): "Designing Weather Insurance Contracts for Farmers in Malawi, Tanzania and Kenya," Discussion paper, IRI.

Osgood, D. E., and K. E. Shirley (2010): "The impacts of thresholds on risk behavior: What's wrong with index insurance?," Discussion Paper 61166, Agricultural and Applied Economics Association, presented at the 2010 Annual Meeting, July 25-27, 2010, Denver, Colorado.

Pan, L. (2009): "Risk Pooling through Transfers in Rural Ethiopia," *Economic Development and Cultural Change*, 57, 809–835.

Papon, T. (2008): "The Effect of Pre-commitment and Past-Experience on Insurance Choices: An Experimental Study," *The Geneva Risk and Insurance Review*, 33(1), 47–73.

Patrick, G. F. (1988): "Mallee Wheat Farmers' Demand for Crop and Rainfall Insurance," *Australian Journal of Agricultural Economics*, 32(01).

Patt, A., N. Peterson, M. Carter, M. Velez, U. Hess, and P. Suarez (2009): "Making index insurance attractive to farmers," *Mitigation and Adaptation Strategies for Global Change*, 14(8), 737–753.

Patt, A., P. Suarez, and U. Hess (2010): "How do small-holder farmers understand insurance, and how much do they want it? Evidence from Africa," *Global Environmental Change*, 20(1), 153 – 161, Adaptive Capacity to Global Change in Latin America.

Paulson, N. D., and C. Hart (2006): "A Spatial Approach to Addressing Weather Derivative Basis Risk: A Drought Insurance Example," 2006 Annual meeting, July 23-26, Long Beach, CA 21249, American Agricultural Economics Association (New Name 2008: Agricultural and Applied Economics Association).

Pope, R. D., and R. E. Just (1991): "On testing the structure of risk preferences in agricultural supply system," *American Journal of Agricultural Economics*, pp. 743–748.

Quiggin, J., G. Karagiannis, and J. Stanton (1993): "Crop Insurance and Crop Production: an Empirical study of Moral Hazard and Adverse Selection," *Australian Journal of Agricultural Economics*, 37(02).

Ramsey, F. P. (1926): "Truth and Probability," in *The Foundations of Mathematics and other Logical Essays*, ed. by R. B. Braithwaite, chap. 7, pp. 156–198. McMaster University Archive for the History of Economic Thought.

Ravallion, M., and S. Chaudry (1997): "Risk and insurance in Village India: Comment," *Econometrica*, 65(1), 171–184.

Reardon, T., and J. E. Taylor (1996): "Agroclimatic shock, income inequality, and poverty: Evidence from Burkina Faso," *World Development*, 24(5), 901–914.

Rosenzweig, M. R. (1988): "Risk, Implicit Contracts and the Family in Rural Areas of Low-Income Countries," *The Economic Journal*, 98(393), 1148–1170.

Rosenzweig, M. R., and H. P. Binswanger (1993): "Wealth, Weather, Risk and the Composition and Profitability of Agricultural Investments," *The Economic Journal*, 103(416), 56–78.

Rosenzweig, M. R., and K. I. Wolpin (1993): "Credit Market Constraints, Consumption Smoothing and the Accumulation of Durable Production Assets in Low Income Countries: Investiements in Bullocks in India," *The Journal of Political Economy*, 101(2), 223–244.

Roudier, P., B. Sultan, P. Quirion, C. Baron, A. Alhassane, S. B. Traor, and B. Muller (2012): "An ex-ante evaluation of the use of seasonal climate forecasts for millet growers in SW Niger," *International Journal of Climatology*, 32(5), 759–771.

S. Dercon, M. Kirchberger, J., and J. Platteau (2008): "Literature Review on Microinsurance," Discussion paper, ILO, Microinsurance paper.

Sandmo, A. (1971): "On the Theory of the Competitive Firm under Price Uncertainty," *American Economic Review*, 61(1), 65–73.

Sarris, A., P. Krfakis, , and L. Christiaensen (2006): "Producer Demand and Welfare Benefits of Rainfall Insurance in Tanzania," Discussion paper, FAO, Rome, No 18.

Savage, L. J. (1954): *The Foundations of Statistics*. John Wiley and Sons, New York.

Shynkarenko, R. (2007): "Introduction of Weather Index Insurance in Ukraine - Obstacles and Opportunities," 101st Seminar, July 5-6, 2007, Berlin Germany 9244, European Association of Agricultural Economists.

Siebert, A. B., and M. N. Ward (2011): "Future Occurrence of Threshold-Crossing Seasonal Rainfall Totals: Methodology and Application to Sites in Africa," *journal of applied meteorology and climatology*, 50.

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.

Skees, J. R., S. Gober, P. Varangis, R. R. Lester, and V. Kalavakonda (2001): "Developing Rainfall-Based Index Insurance in Morocco," *SSRN eLibrary*.

Spinnewijn, J. (2012): "Heterogeneity, Demand for Insurance and Adverse Selection," CEP Discussion Papers dp1142, Centre for Economic Performance, LSE.

Stein, D. (2011a): "Paying Premiums wit the insurer's Money: How Loss Aversion Drives Dynamic Insurance Decisions," Discussion paper, LSE.

Stein, D. (2011b): "Paying premiums with the insurers money: How loss aversion drives dynamic insurance decisions," Mimeo.

Suri, T. (2011): "Selection and Comparative Advantage in Technology Adoption," *Econometrica*, 79(1), 159–209.

Tanaka, T., C. F. Camerer, and Q. Nguyen (2010): "Risk and Time Preferences: Linking Experimental and Household Survey Data from Vietnam," *American Economic Review*, 100(1), 557–71.

Thomas, A.-C., M. Delpierre, and B. Verheyden (2011): "Wealth Differentiated Risk Management Strategies. Evidence from Madagascar," Discussion paper, UCL.

Townsend, R. M. (1994): "Risk and Insurance in Village India," *Econometrica*, 62(3), 539–591.

Udry, C. (1995): "Risk and Saving in Northern Nigeria," *The American Economic Review*, 85(5), pp. 1287–1300.

Udry, C. (2010): "The Economics of Agriculture in Africa: Notes Toward a Research Program," mimeo, Yale University.

Vedenov, D. V., and B. J. Barnett (2004): "Efficiency of Weather Derivates as Primary Crop Insurance Instruments," *Journal of Agricultural and Resource Economics*, 29(3), 387–403.

von Neumann, J., and O. Morgenstern (1947): *Theory of Games and Economic Behavior*. Princeton University Press, Princeton.

Wang, H. H., L. D. Makus, and C. X. (2004): "The impact of US Commodity Programmes on hedging in the presence of Crop Insurance," *European Review Agricultural Economics*, 31, 331–352.

Woodard, J. D. (2011): "Impacts of Weather and Time Horizon Selection on Crop Insurance Ratemaking: A Conditional Distribution Approach," 2011 Annual Meeting, July 24-26, 2011, Pittsburgh, Pennsylvania 103929, Agricultural and Applied Economics Association.

Woodward, J. (2011): “Impacts of Weather and Time Horizon Selection on Crop Insurance Ratemaking: A Conditional Distribution Approach,” Discussion paper, Pittsburg EAAE joint annual meeting presentation.

Zant, W. (2008): “Hot Stuff: Index Insurance for Indian Smallholder Pepper Growers,” *World Development*, 36(9), 1585–1606, 0305-750X.

Zeitlin, A., S. Caria, R. Dzene, P. Jansk, E. Opoku, and F. Teal (2010): “Heterogeneous returns and the persistence of agricultural technology adoption,” CSAE Working Paper Series 2010-37, Centre for the Study of African Economies, University of Oxford.

Zimmerman, F. J., and M. R. Carter (2003): “Asset Smoothing, Consumption Smoothing and the Reproduction of Inequalities under risk and Subsistence Constraints,” *Journal of Development Economics*, 71, 233–260.