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**Agricultural Insurances
Based on Meteorological
Indices: Realizations,
Methods and Research
Agenda**

By **Antoine Leblois**, CIRED (Centre International de Recherche sur l'Environnement et le Développement), France

Philippe Quirion, CIRED, CNRS, LMD-IPSL (Laboratoire de Météorologie Dynamique – Institut Pierre-Simon Laplace), France

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By Antoine Leblois, CIRED (Centre International de Recherche sur l'Environnement et le Développement), France

Philippe Quirion, CIRED, CNRS, LMD-IPSL (Laboratoire de Météorologie Dynamique – Institut Pierre-Simon Laplace), France

Summary

In many low-income countries, agriculture is mostly rain-fed and yields highly depend on climatic factors. Furthermore, farmers have little access to traditional crop insurance, which suffers from high information asymmetry and transaction costs. Insurances based on meteorological indices could fill this gap since they do not face such drawbacks. However their implementation has been slow so far. In this article, we first describe the most advanced projects that have taken place in developing countries using these types of crop insurances. We then describe the methodology that has been used to design such projects, in order to choose the meteorological index, the indemnity schedule and the insurance premium. We finally draw an agenda for research in economics on this topic. In particular, more research is needed on implementation issues, on the assessment of benefits, on the way to deal with climate change, on the spatial variability of weather and on the interactions with other hedging methods.

Keywords: Agriculture, Insurance, Climatic Risk

JEL Classification: G21, O12, Q12, Q18, Q54

Address for correspondence:

Antoine Leblois
CIRED (Centre International de Recherche sur l'Environnement et le Développement)
45 bis avenue de la Belle Gabrielle
F 94736 Nogent sur Marne
France
E-mail: leblois@centre-cired.fr

Agricultural insurances based on meteorological indices: realizations, methods and research agenda

Antoine Leblois* & Philippe Quirion†

Abstract

In many low-income countries, agriculture is mostly rainfed and yields highly depend on climatic factors. Furthermore, farmers have little access to traditional crop insurance, which suffers from high information asymmetry and transaction costs. Insurances based on meteorological indices could fill this gap since they do not face such drawbacks. However their implementation has been slow so far.

In this article, we first describe the most advanced projects that have taken place in developing countries using these types of crop insurances. We then describe the methodology that has been used to design such projects, in order to choose the meteorological index, the indemnity schedule and the insurance premium. We finally draw an agenda for research in economics on this topic. In particular, more research is needed on implementation issues, on the assessment of benefits, on the way to deal with climate change, on the spatial variability of weather and on the interactions with other hedging methods.

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*CIRED (Centre International de Recherche sur l'Environnement et le Développement), leblois@centre-cired.fr, 45 bis avenue de la Belle Gabrielle F 94736 Nogent sur Marne cedex , +33 1 43 94 73 67.

† CIRED, CNRS, LMD-IPSL (Laboratoire de Météorologie Dynamique – Institut Pierre-Simon Laplace), Paris.

Table of contents

| | |
|--|-----------|
| Introduction | 3 |
| 1 The main experiments in developing countries to date | 4 |
| 1.1 India | 4 |
| 1.2 Malawi | 5 |
| 1.3 Ethiopia | 5 |
| 2 Methods | 6 |
| 2.1 Meteorological indices | 6 |
| 2.1.1 Basic rainfall indices | 6 |
| 2.1.2 Water stress indices | 7 |
| 2.1.3 Mechanistic crop models | 7 |
| 2.1.4 Drought indices | 7 |
| 2.1.5 Satellite imagery data | 8 |
| 2.1.6 Index choice criteria | 8 |
| 2.2 Insurance policy design | 8 |
| 2.2.1 Typical indemnity schedule | 8 |
| 2.2.2 Optimization of policy parameters | 9 |
| 2.2.3 Computing the expected value and distribution of the indemnity | 9 |
| 2.2.4 Loading factor calibration | 10 |
| 3 A research agenda | 11 |
| 3.1 Implementation issues and institutional aspects | 11 |
| 3.2 Assessment of the benefits | 12 |
| 3.2.1 Quantifying the benefits of a lower income variability | 12 |
| 3.2.2 Intensification of production | 13 |
| 3.2.3 Modelling poverty traps mechanisms | 13 |
| 3.3 Robustness to climate change | 14 |
| 3.4 Climate spatial variability and the scaling of insurances | 14 |
| 3.5 Interactions with other hedging methods | 15 |
| 3.5.1 Informal practices | 15 |
| 3.5.2 Inputs loan | 16 |
| 3.5.3 Seasonal weather forecasts | 17 |
| Conclusion | 18 |
| References | 19 |

Introduction

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). Since the farmer benefits from an information asymmetry vis-à-vis the insurer, the latter must resort to a costly damage assessment to check at least part of the claims. 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.*, 2007). Unfortunately, Least Developed Countries (LDC) governments do not have the financial resources to finance these subsidies at a large scale.

Insurances Based on Meteorological Indices (IBMIs) may constitute an interesting alternative, especially for LDCs. 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 correlated to crop yield. IBMIs were initiated by agricultural economists debating on their attractiveness for wheat producers in Australia (Bardsley and Davenport, 1984, Quiggin 1986, Patrick, 1988). The idea was then applied to LDCs with the aim of developing the agricultural sector (Skees *et al.*, 1999) and a formal framework was provided by Mahul, 2001. IBMIs are analogous to weather derivatives, which appeared in the 1990s in the energy sector. Those financial products reduce the impact of a harmful weather on firms whose margins widely depend on climate, such as energy suppliers.

The main advantage of IBMIs over traditional insurance is that there is no need for damage assessment. Thanks to the absence of information asymmetry (Goodwin and Mahul, 2004) the principal (the insurer) does not have to check the agent's (the insured farmer) statement. Moreover, IBMIs allow a quick payment of the indemnity (Alderman and Haque, 2006), provided that the organization producing the weather data is efficient enough, as noticed by Giné *et al.*, 2008 on the Indian case.

The downside is the so-called basis risk, *i.e.* the fact that the correlation between crop yield 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 slope, the soil quality, and the availability of alternative water sources. Moreover, many hazards independent of the weather, such as pests, do impact yields, especially in LDCs. Finally, a high spatial variability of the weather (section 3.4 below) 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.

The scientific literature on IBMIs is developing quickly. Several recent papers present the main IBMIs implemented: cf. Barnett *et al.*, 2007, Barnett *et al.*, 2008 and Collier *et al.*, 2009.

Others focus on a particular project or region: for example, Berg *et al.* (2009) focus on Burkina Faso, Giné *et al.* (2007, 2008) on India, Hess and Syroka (2005) on Malawi, Mahul and Skees (2007) on Mongolia, Turvey, 2001 on Ontario (Canada). Some papers deal with one aspect of the IBMIs: Barnett *et al.* (2008) with the ability of IBMIs to tackle poverty traps, Chantarat *et al.* (2007) with their contribution to famine prevention, Hochrainer *et al.* (2007) with their robustness to climate change.

In this paper, we provide a general overview of the methods used and difficulties faced by IBMIs. In a first part, we describe the main IBMI experiments in developing countries, i.e. in India, Malawi and Ethiopia. In part two, we present the methods used to design the key features of an IBMI. In the third part, we draw an agenda for economic research on IBMIs. Given the focus of the present journal, we voluntarily oriented our work towards the reduction of risk in rural areas of developing countries more than towards the optimization of risk management in rich countries agricultural sector.

1 The main experiments in developing countries to date

Most IBMI projects implemented in developing countries aim at insuring individual farmers. Malawi and India are currently the countries with the biggest experience. In this part, we also present a rather different kind of IBMI, which was implemented in Ethiopia at a ‘macro’ scale.

1.1 India

India is the country with the most extensive experience of IBMI as around 150,000 clients purchased a private insurance policy and about 700,000 a public one (Barrett *et al.*, 2009). The public IBMI, called *Varsha Bima*, was included in 2007 the National Agricultural insurance Scheme, itself implemented by a paragonovernmental insurance organization: the Agricultural Insurance Company of India. In that frame, indemnifications for farmers are triggered by deficit and excess of rainfall during the Kharif (monsoon season) and high temperatures and frost during the Rabi, the winter growing season.

We focus here on the private initiative jointly offered by an insurance company (ICICI Lombard) and a local micro-finance institution (BASIX), the first IBMI implemented at a large scale. The policy scheme began in 2003 in Andhra Pradesh, covering groundnut and castor crop against drought on three phenological phases of the monsoon season. Farmers can purchase separate contracts for each phase. It was limited to farmers who contracted a loan to BASIX until 2004. It was then extended to non-borrowing farmers and to other regions (36 districts within 8 Indian states) and other crops (cotton, oranges and others). Insurance distribution was benefiting from the micro-finance institution networks and their design from the expertise and subsidies of international organizations, such as the Commodity Risk Management Group (CRMG) of the World Bank.

However the results of the policy have to be put into perspective in regard to the low premiums (less than US\$5 per acre, Giné et al, 2007) and very low observed subscription rate of such experiments (less than 3% in Andhra Pradesh and less than 20% in Gujarat according to Giné *et al.*, 2008). Those experiments lead to statistical studies about insurance take-up and especially its determining factors (Cole *et al.*, 2009, Giné *et al.*, 2007 and Giné *et al.*, 2008, cf. section 3.1).

1.2 Malawi

In Malawi, two projects jointly offering an IBMI with a credit for high quality seeds were run by the Insurance Association of Malawi in association with a cooperative of local growers (cf. section 3.5.2). 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 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 (2006-2007) was spread out over the whole country; it was extended to maize producers and for the first time the loan is also able to be used for the purchase of fertilizers. 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. The impact of this program could not be estimated due to a good rainy season in 2006.

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 WFP major donors and the product was insured by the reinsurance company AXA Re (now PARIS Re). If any indemnity had been paid, it would have been redistributed by the Ethiopian government to about 60,000 households in 2006 and 316,000 in 2008 (Barrett *et al.*, 2009) that cultivate wheat, millet, cowpea and maize.

The index was based on the cumulative rainfall, computed with a network of 26 meteorological stations across the country. The complex annual rainfall pattern in Ethiopia pointed out the necessity to go thoroughly into growing strategies. Indeed, 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 one long-cycle crop or to sow two different short-cycle crops.

There are also many other programs in pilot phase, in development or discontinued in Argentina, Bangladesh, Canada, China, Ethiopia, Honduras, Kazakhstan, Kenya, Madagascar, Mali, Nicaragua, Ukraine, Senegal, South Africa, Tanzania, Thailand, Vietnam and Zambia (cf. Bruin *et al.*, 2009 and Barnett *et al.*, 2008). These experiences cannot be presented here because of space constraints.

2 Methods

2.1 Meteorological indices

To minimize the basis risk, the chosen meteorological index has to be a good predictor of yields, and especially of bad yields. Some products insure against cold temperatures or frost (South Africa), others against excess of water during harvest (India) or against floods (Vietnam), but most of them insure against a lack of rain. Hence, we only study the last category in this section.

2.1.1 Basic rainfall indices

- The 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 split in several sub-periods, generally 3 to 7, and an indemnity is paid whenever a lack of rain occurs in one of these sub-periods. It was the case in the Malawian and the Indian experiments (cf. §1.3 and §1.4). 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/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 indices were applied in India and during the first Malawian experiment. They 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. In a nutshell, available water is estimated by 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.

These indices are better predictors of yields if they are computed using the actual sowing date (or a sowing window) to trigger the beginning of the growth cycle. Imposing an arbitrary sowing date or window in the insurance policy increases the basis risk hence reduces the benefit of the IBMI. However, inquiring after actual sowing date would be very costly. Hence, in practice, especially in India and Malawi, the sowing date used to determine the crop growth phases is imposed by the insurer.

2.1.2 Water stress indices

Water stress indices are based on the idea that crop yields are proportional to the satisfaction of crop needs for water resource. The Water Resource Satisfaction Index (WRSI) is the main water stress index. It is defined as the ratio of actual evapotranspiration (ETa) to maximum evapotranspiration (ETM). ETa corresponds to an estimation of the quantity of water actually evaporated while ETM 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 IBMI schemes in India and in the second Malawi experiment, computed on a 10-days period.

2.1.3 Mechanistic crop models

Mechanistic dynamic models simulate crop physiological growth depending on available environmental factors. Their precision in yields estimation is in theory greater, but they need very detailed input data, particularly time series at the field 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.*, 2006 in Nicaragua. It is however difficult to use such complex models (Osgood *et al.*, 2007) because of a high sensitivity to parameters calibration. On the other hand they can be used to assess the shortcomings of other methods. They also allow yield simulation under higher levels of inputs than actually used by the farmers, which is useful since IBMIs may create an incentive for such intensification that is unobservable *ex ante* (cf. § 3.2.3).

2.1.4 Drought indices

Those indices use temperatures and rainfall to compute 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 IBMI 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 ran on a decadal basis.

2.1.5 Satellite imagery data

Satellite imagery data allows computing vegetation indices such as the Leaf Area Index (LAI) or the Normalized Difference Vegetation Index (NDVI). The latter evaluates crop canopy photosynthesis – more precisely light absorption – calculated from the difference between near infrared and red beams, divided by their sum: $NDVI = (NIR-RED)/(NIR+RED)$. This technique is more and more frequently used for food crisis early warning, livestock management, and forecasts of forage production. It has been implemented by Agriculture Financial Services Corporation (AFSC) in Alberta (Canada), Spain, and Mexico for grassland and forage insurance (Hartell et al., 2006) and by the World Bank in 2005 in Mongolia (Mahul and Skees, 2007) for livestock. The NDVI can hardly discriminate between pastures and cultivated areas and it is computed with a delay period because of the potential presence of clouds. However improvements in this field are very quick so that imagery resolution increases regularly and new technologies could emerge in the near future.

2.1.6 Index choice criteria

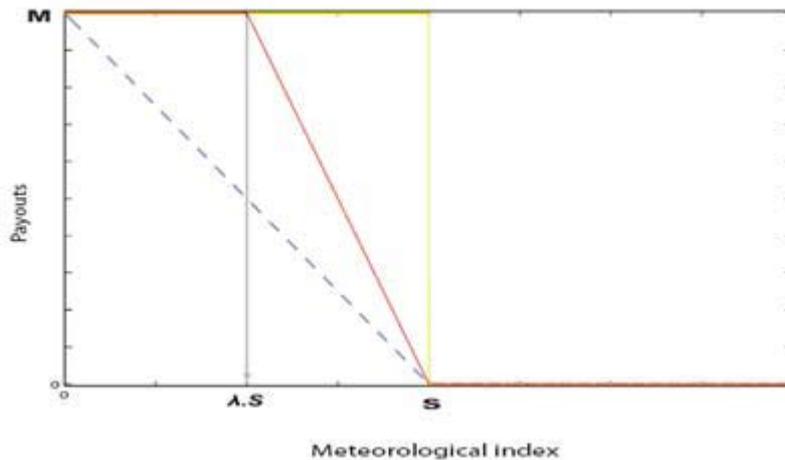
Minimizing the basis risk is the main criterion to compare those indices. The correlation between yields and index values is the simplest way to deal with such a choice, but more complex objective functions exist and are discussed in section 3.2.1. It is fundamental, in order to improve the attractiveness for farmers, to evaluate the correlation between yields and index values for low yields, *i.e.* for situations in which an indemnity should be paid. However, complexity limits the transparency and acceptability of IBMIs and data availability is often limited, especially in developing countries. There is thus a trade-off between index transparency, readability for farmers, data availability and thus simplicity on the one hand, and the index ability to reflect low yields (or minimize the basis risk) on the other hand.

2.2 Insurance policy design

2.2.1 Typical indemnity schedule

As it has been brought forward by Vedenov and Barnett, 2004, the typical indemnity schedule is defined by three parameters (λ, S, M) . The threshold level of the meteorological index, called the strike (S), triggers payouts for insured farmers. A slope related parameter (λ with: $0 < \lambda < 1$) determines the index level: $\lambda.S$, from which payouts are bound to a maximum (M). Figure 1 displays the two opposite insurance contract shapes with λ equalling 0 and 1 (the latter corresponding to a lump sum transfer M) and an intermediary case. The contract shape is based on the fact that crop growth depends positively on the weather index (e.g. water availability), from a maximum stress meaning zero yield, to a point where water is no longer a limiting factor of crop growth.

Figure 1: Usual shapes of IBMI policies.



In many real-world IBMIs, the indemnity schedule is more complex. In particular, as explained above (§2.1.3), partial payouts are computed for each crop growth phase, and the total indemnity is the total of these partial payouts. This is the case in Malawi (Osgood, 2007) and in Senegal (Mahul *et al.*, 2009) or in many Commodity Risk Management Group (CRMG) schemes in India. In this frame, a maximum insurance payout is defined for each growth phase and the sum of insurance payouts is also bounded on the whole growing period.

2.2.2 Optimization of policy parameters

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 value of inputs (fertilizers, seeds, pesticides...) or at the value of the crop in a normal year. For instance, the strike is set according to an agronomic relation linking yields and water availability 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 featuring risk aversion, more precisely a Constant Relative Risk Aversion (CRRA) function (Berg *et al.*, 2009). Others minimize the semi-variance of income after insurance (Vedenov and Barnett, 2004). Income after insurance is the value of observed yield plus the indemnity minus the premium, and the semi-variance is the squared difference of yields inferior to the long-run average yield, relatively to this long run level. Finally, Osgood *et al.*, 2007 minimize the square of the difference between payouts and expected losses, the latter being defined as yields under the first quartile of simulated yield distribution.

2.2.3 Computing the expected value and distribution of the indemnity

The insurance premium depends on the expected value of the indemnity and on a measure of the probability distribution of payouts, *i.e.* indemnities (cf. section 2.2.4 below). There are

two methods to compute these values; Historical Burn Analysis (HBA) and Historical Distribution Analysis (HDA) also called index modelling.

Historical Burn Analysis (HBA) is the simplest method. It consists in converting the historical values (possibly cleaned and detrended, cf. § 3.3.1 below) directly into payouts. HBA gives a first indication of the mean and range of possible payouts of a weather contract, from which parameters such as the expected value and the standard deviation of the payouts can be calculated. Moreover, HBA does not require any assumption on distribution function parameters, contrarily to HDA. The disadvantage of HBA is that it gives a limited view of possible index outcomes: it may not capture the possible extremes, and it may be overly influenced by individual years and measurement errors in the historical dataset (World Bank, 2005).

Historical Distribution Analysis (HDA) consists in fitting a statistical distribution function to the historical values and converting values from this distribution to payouts. The distribution has to be postulated. The expected payout and the measures of the risk, such as standard deviation and VaR_{99} , (cf. §2.2.5 below) can be calculated either by Monte-Carlo simulations from the distribution or, for simple distributions and indemnity schedules, analytically (World Bank, 2005). Rare events even if not present in the historical series are treated in a better way with this method. Moreover outliers and measurement errors will have less of an impact on results than they do in the case of HBA.

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 postulated in the HDA method.

2.2.4 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 of the risk taken by the insurer. We will only discuss the second item here. The cost of the risk for the insurer depends on the correlation of this particular risk with the pre-existing risk portfolio of the insurer (Meze-Hausken *et al.*, 2009). Abstracting from this idiosyncratic element, two methods are used for evaluating the additional cost of risk taking (Henderson, 2002):

- In the Sharpe ratio method, the margin is proportional to the standard deviation of cost ($\delta(i)$, with i the indemnities) for the insurer:

$$\alpha \times \delta (i) \tag{1}$$

Where α is the Sharpe ratio.

- In the Value at Risk (VaR), this margin is proportional to a risk of a defined occurrence probability. For example, VaR₉₉ is the cost of the event that occurs with a probability of 1%:

$$\beta \times [\text{VaR}_{99} - E(i)] \quad (2)$$

The latter method is more adapted to high risk with low probability and cannot be applied with HBA (cf. 2.2.3 above). An ex post statistical analysis on a case study in India, run by Giné *et al.*, 2007, shows 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 deal with IBMI 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 and a final premium rate of 11% (Hess and Syroka, 2005).

3 A research agenda

3.1 Implementation issues and institutional aspects

A pre-existing distribution network, like that of a financial institution, reduces marketing costs. This factor and farmers' trust in supplying institutions could be understood as the major factors of the success of Indian programs. There is a crucial need to link the very low subscription rate in pilot projects to theoretical assumptions. The literature mainly raised the effect of human capital or other capacity barriers in empirical works. In particular, Giné and Yang (2009) point out the role of educational background in the particular case of a joint supply of insurance and loan in Malawi.

The first reason given by farmers that could explain the low take-up is the misunderstanding about the product (Giné, 2008). The authors found that the take-up rate falls with the extent to which household credit constraint binds and more surprisingly with a self-reported risk aversion indicator. The only explanation of this latter effect is that uncertainty about the product reliability drives the take-up choice. Cole *et al.*, 2009 point out the trust in the supplying institution and credit constraints as explanations of low take-up rates. Many on-going studies (for instance the EUDN ILO program: microinsurance innovation facility¹ granted many demand related research topics) are concentrating upon trust, readability of the underlying index and the contract, transparency of the process from index measure to funding.

Farmers' acceptance and perceptions about the product are also at stake in explaining the low take-up rates. Perceptions are also linked to capacity issues; the role of the apprehension of probability seems to be embedded with bounded rationality. Patt *et al.*, 2009 list recent field studies and theoretical models explaining insurance attractiveness and farmers trust insisting

¹ <http://www.ilo.org/public/english/employment/mifacility/activities/research/grants.htm>

on commercial supplier honesty and his will to improve production conditions. Patt *et al.*, 2010 compare the impact of traditional communication tools such as oral or written presentations of indexed contracts relatively 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 relatively to oral or written presentations. According to the authors, the misunderstanding of insurance policies after training could be due to an insufficient educational background. They also observed existence of an ‘endowment effect’ brought forward by the prospect theory, which would justify to go beyond the expected utility approach.

There are also many institutional barriers restraining IBMI implementation. It is in particular crucial that the country institutional framework and regulatory environment be adapted to private insurers, *e.g.* allowing contract enforcement at low costs (Carpenter and Skees, 2005 and Henderson, 2002). It is the case of South Africa, India (Indian Insurance Regulatory and Development Authority, IRDA), Peru and the Philippines (Insurance Commission of the Philippines: Insurance Code of 1974) that adapted their legislations to facilitate private micro-insurance initiatives (Wiedmaier-Pfister and Chatterjee, 2006).

3.2 Assessment of the benefits

3.2.1 Quantifying the benefits of a lower income variability

The IBMI literature includes almost exclusively ex-ante analyses, and the rare ex-post empirical analyses are either very descriptive (Giné, 2007) or focused on the explanation of participation (Giné, 2008) and technology adoption (Giné *et al.*, 2009).

Ex ante analyses are either based on expected utility or on the minimization of a risk indicator. Berg *et al.* (2009) rely on expected utility maximization and find an increase of certainty equivalent income of about 0.5 to 3%, depending on the cultivated crop: gains for millet and sorghum growers are very low, but gains for groundnut and maize growers are more significant. Vedenov and Barnett (2004) minimize several risk indicators, including the semi-variance of the insured revenue and the value-at-risk (VaR). Both papers also demonstrate the risk of over-fitting the data when the same dataset is used for optimizing the contract parameters and for quantifying the benefits: in several simulations, an IBMI yields a seemingly good outcome when applied to the dataset on which it was optimized, but a much poorer outcome when applied to another dataset for validation.

Breustedt *et al.*, 2008 review the tools used for evaluating risk reduction through IBMIs. They note that such downside loss risk measures, as well as the mean-variance criterion, overestimates the benefit of purchasing crop insurance. They highlight the scarcity of works

that deal with farm-level yields and the need for analyses of risk reduction at the level of individual farmers.

The challenge is to quantify the risk reduction and to compare it with the reduction in average income due to the presence of a loading factor. Risk minimization is indeed costly in terms of average income level as long as there is a non-subsidized loading factor. Downside risk measures, that only incorporate the risk minimization objective, are thus insufficient if the insurance has a price higher than the actuarial fair rate. There is still a need for weighting risk reduction and average income level in the utility function (either a risk aversion parameter in the expected utility case or an ad-hoc parameter in the case of the mean-variance criterion).

3.2.2 Production intensification

Limited wealth prevents farmers from implementing risky strategies that are more productive on average: use of fertilizers, improved cultivars, etc. Binswanger and Rosenzweig, 1993 evaluate at 30% the average shortfall in farm profit of Indian farmers that undertake low risk / low yields productive choices due to risk aversion. Farm models and farmers' risk management are thus also needed to acknowledge the use of intensifying techniques that seem to be a cornerstone in increasing yields.

Insured farmers could be incited to undertake more risky growing strategies and thus to adopt new technologies and invest in fertilizers. The incitation to intensify the production process is part of the interest of such products, in spite of its assessment complexity in absence of large scale empirical data. There is a real need for *ex-post* impact assessment taking into account those endogenous impacts of IBMI implementation.

Yields time series with different levels of fertilizers and different crops and varieties can be simulated by crop models for estimating potential production under various weather conditions. Such models are typically calibrated on the potential yields observed in experimental stations. However, in LDCs, real-farm yields are much lower than potential yields observed in experimental stations, for various reasons: pests, lack of available labour at crucial stages, low availability of inputs... For instance quality mineral fertilizer distribution seem to be quite slow to emerge in spite of a poor soil fertility; see Duflo *et al.*, 2009 for a review of underlying mechanisms.

3.2.3 Modelling poverty traps mechanisms

Poor households are facing a double constraint constituted of a tied budget (limited access to credit market) and a subsistence imperative. Often, in order to reach minimum nutritional needs, households under-invest in productive capital, including in human capital through health and education expenditures. Facing risk indeed creates an incentive for poor households to stock non-productive subsistence assets (food) with low-return and low-risk (Zimmerman and Carter, 2003, cf. also section 3.5.1 for a short review of the impact of other

informal risk coping strategies). According to Chetty and Looney (2006), consumption smoothing mechanisms and especially their cost should thus be inquired when assessing the welfare gain of any social insurance. Barnett *et al.*, 2008 review such mechanisms and their crucial role in designing index based risk transfer products. However, to our knowledge, no IBMI has been assessed within a formal dynamic model featuring the possibility of poverty traps.

3.3 Robustness to climate change

Due to global warming, there is an upward trend in local temperatures in almost every region in the world. If the index of an IBMI includes temperatures but does not account for this trend, the calculation of the expected indemnity is biased. The continuation of the 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 and 5.8 °C, depending both on climate sensitivity and on greenhouse gas emissions. Second, uncertainty on local warming is 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, to natural climate variability and/or to changes in land use. The difficulty is higher than for temperature since in many regions, like again West Africa, climate models diverge on whether global warming will entail an increase or a decrease in rainfall. Moreover, not only the average, but also the inter-annual variability of the rainfall level may change due to global warming.

Simple detrending methods, based on past data, are routinely used in IBMI 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 on future local climates. Hence, the presence of a trend in the data used to build the index can incite private suppliers to turn away from local markets. It was the case in Morocco (Skees *et al.*, 2001) in spite of the twenty years of precipitations data and the provision promises made by the government.

Hochrainer *et al.*, 2007 test the robustness of an IBMI in Malawi using climate forecasts generated by the MM5 and PRECIS regional climate models and put into question its long run sustainability until 2080.

3.4 Climate spatial variability and the scaling of insurances

Risk covariance is a major source of insurance market failure in LDC's and explains the high subsidization rate of agricultural insurances, according to Barnett *et al.* (2008).

Spatial risk correlation is a major impediment of IBMI 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 make a HDA studying insurance provision on 30 years and 15 stations and conclude that pooling over the country limits the need for capital requirement at the beginning of the period.

Spatial variability reduces this problem but increases the basis risk for a given rain gauge network density. In practice the maximum distance to the nearest meteorological station is set between 20 and 30 km (20 km in Malawi and Senegal, and until 30 in most cases in India and in Canada according to Hartell *et al.*, 2006). Increasing the density of rain gauges raises substantially IBMI management costs (installation, operation and maintenance) creating a trade-off between the management cost and the basis risk.

In most IBMIs, only the closest meteorological station is taken into account to compute 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 ones² to stochastic ones as such as Kriging, based on Gaussian multivariate statistical distributions.

3.5 Interactions with other hedging methods

Before listing possible complementarities with other formal hedging methods, we first discuss the potential substitution with existing informal methods that deal with risk-bearing (Arnott and Stiglitz, 1991, Bloch *et al.*, 2008). One has also to recall that potential substitutability with risk mitigation strategies, such as infrastructures investments (for example irrigation projects) that could be crowded out by insurance supply, is also able to limit the scope of such products.

3.5.1 Informal practices

We distinguish between risk management (or mitigation: *ex ante*) and risk coping (or adaptation: *ex-post*) methods following Dercon, 2005. Since Besley, 1995 and Fafchamps, 2003 already reviewed the literature on those informal methods, we only mention them briefly below.

² Simple linear weighting, decreasing with distance of stations around or squared weighting like the Inverse Distance Weighted Averaging (IDWA).

Risk coping

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 importance for IBMIs literature was recently analyzed by Barnett *et al.*, 2008. Farmers are incited to pool spatially the risks they face for instance by using private transfers. Pan, 2008 however found evidence that transfers have a minor impact on risk pooling. Kazianga and Udry, 2006 only found evidence of a very low risk sharing among households facing climatic shocks in Burkina Faso. A potential explanation is that having recourse to informal credit could also be very costly (Collins *et al.*, 2009).

Risk management

Other beforehand strategies such as self-insurance (savings, livestock and other stocks adjustment such as mortgage of personal goods, Collins *et al.*, 2009) crop choice, intercropping are also a possible substitution.

Empirical studies point out the very low use of livestock as a buffer stock (Fafchamps *et al.*, 1998, Lybbert *et al.*, 2004, Lentz et Barrett, 2005 et Unruh, 2008). They rely almost exclusively on self-insurance and smooth consumption by adjusting stocks of stored grain that could also be very costly. For instance stored grain undergoes very high depreciation rates associated with different degradation sources, such as moisture, rodents and insects.

Finally we can argue that the cost of both informal methods limit their attractiveness especially as compared to formal insurance products. Dercon *et al.*, 2008 review the works evaluating those cost, highlighting the need for health and crop micro-insurances.

3.5.2 Inputs loan

Combination of insurance with input credits represents a double interest. First it allows the use of the distribution networks of micro-finance institutions. Then it mitigates the default risk for lenders, lowering credit interest rate all other things being equal. The joint effect of both products, with a possible farmers' default on loan is formalized by Dercon and Christiaensen, 2007 in the Ethiopian context. Lowering the default rate indeed reduces the potential moral hazard and adverse selection induced by loans supplied at a given interest rate. Screening and monitoring costs thus drop, lowering loans prices. Finally providing a mandatory insurance jointly with a product that is far more expensive limits the adverse selection that lies in the insurance product by limiting the incitation for risky producers to buy insurance product.

Giné and Yang, 2009 however show evidence that loan for high-yielding hybrid maize and groundnut seeds in Malawian field does not increase the take-up rate and even possibly lower it. To reach this conclusion they run a randomized experiment comparing take-up rates of

farmers that subscribe to a loan with a mandatory IBMI priced at an actuarially fair rate to those of a control group for whom a loan without insurance was supplied. The use of high-yielding seeds rose compared to the previous years but, surprisingly, insurance seems to have had a negative impact (by roughly 13 percentage points) on loan take-up. A potential explanation mentioned by the authors is that farmers already are implicitly insured by the limited liability serving as collateral in the loan contract. However, the low number of observations and a significantly higher educational level in the control group are limiting the scope of such results.

3.5.3 Seasonal weather forecasts

Seasonal weather forecasts provide probabilistic information on the next season in various regions of the world. If these forecasts become more accurate in the future, farmers could adjust their productive choices according to the forecasts. In particular, they may use more risky but potentially more productive crops or techniques in years with a good forecast. Meza *et al.* (2008) provide a survey on the assessments of the value of these forecasts in agriculture.

Forecasts are necessarily imperfect so that weather related risk remains. In this context, insurance may be a complement for weather forecasts by allowing production intensification with limited risk. Carriquiry and Osgood (2008) and Osgood *et al.* (2008) study the synergies of insurance and seasonal weather forecasts.

Conclusion

Although index-based insurances have gained a growing attention in the last ten years, a lot of research remains to be done before a robust conclusion on their potential benefit can be reached. A part of this research is mainly related to agro-meteorology (e.g. the work on new and improved indices, including the use of data from satellites) but further research in economics is also needed, in at least five directions.

First, there is a need to explain the often low subscription rates and why they differ across projects. Cultural and institutional issues clearly matter here. Second, the quantification of benefits is still in its infancy. Third, although weather insurance is sometimes presented as an adaptation tool against climate change, global warming can threaten the viability of index-based insurances. Fourth, spatial issues, such as the optimal density of weather stations and the ambiguous impact of spatial covariance deserve more attention. Last but not least, the interactions with other hedging methods should be explored further.

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