Agricultural Microinsurance: Managing Weather Risk with Index Insurance in Developing Countries

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Introduction

Weather risk impacts individuals, corporations, and governments with varying degrees of frequency, severity, and cost. Around the world, people face the vagaries of the weather on a daily basis. Moreover, the economy of a country is also at risk to weather through business interruption, supply shocks, diversion of domestic investment from productive activities to mitigation of the disasters' impacts and, for some countries, a reduction in foreign investment in the aftermath of an extreme weather-related event. While often such effects are reversible and short-term, the impact on the economy of a poor country can be significant and long lasting. Evidence from sixteen Caribbean countries shows, for example, that one percentage point of GDP in direct damage from natural disasters can reduce GDP growth by half a percentage point in the same year (Auffret, 2003). Furthermore, the humanitarian cost of weather-related disasters is also greater in the developing world: approximately 80 percent of all fatalities due to weather disasters between 1980 and 2003 occurred in the "uninsured world," comprising predominantly low-income countries (Loster 2004).

Index-based weather insurance is a relatively new product, and the use of weather risk management products in the agricultural sector is still in its infancy, with very few publicized transactions in the United States and Europe. A number of agricultural transactions have occurred outside of the main weather market trading hubs, however, most notably in Canada (Ontario-maize; Alberta-forage), Argentina (Sancor-dairy), South Africa (Gensec Bank-apple cooperative freeze cover), and India (ICICI Lombard-groundnut, cotton, coriander, and orange).

Developing index insurance products is extremely important to reduce the vulnerability of poor rural people to extreme weather events that can be devastating to agricultural productivity.

Weather-indexed insurance is a financial product based on local weather indices that are closely correlated to local yields. Protection from weather-related risks would put poor rural people in a better position to preserve their livelihoods and engage in activities that could increase their incomes.

The main objective of this project is to study how to manage weather risk along with development of weather-indexed insurance products in Africa. The project focuses on (1) the review of existing literature about how weather risk management instruments could be developed for and used in the agricultural sector; (2) relative advantages and disadvantages of index insurance; (3) designing the weather index insurance; (4) pricing of weather risk management instruments.

Though insurers and reinsurers have been showing greater interest in covering weather risk in emerging markets, they face many challenges such as weak primary insurance markets and undeveloped regulatory and financial systems. However, development and implementation of this type of insurance can help the poor cope better when extreme weather hits and can open the door to other financial services, in particular credit.

II. Evaluating the Potential for Weather Index Insurance in Agriculture

A. Problems associated with traditional crop insurance in developing countries.

Agricultural risk is associated with negative outcomes stemming from imperfectly predictable biological, climatic and price variables. Although providing insurance in agriculture is very important, there are several factors that makes insurance inefficient. Spatial correlated risk, moral hazard, adverse selection and high administrative costs are all important reasons why agricultural insurance markets may fail.

1. *The lack of statistical independence in agricultural risks*. In contrast, insurance is an appropriate risk management solution for independent risks. Skees and Barnett (1999) refer to these risks as "in-between" risks. According to Ahsan, et al. (1982), "good or bad weather may have similar effects on all farmers in adjoining areas," and consequently, "the law of large numbers, on which premium and indemnity calculations are based, breaks down." In general, the more the losses are positively correlated, the less efficient traditional insurance is as a risk-transfer mechanism.
2. *Asymmetric information*. In this case, the insured has more knowledge about his or her own risk profile than does the insurer and consequently, it causes two problems: adverse selection and moral hazard. In the case of adverse selection, farmers have better knowledge than do the insurers about the probability distribution of losses and as a result, only farmers bearing greater risks will purchase premium, thus generating an imbalance between indemnities paid and premiums collected. Moral hard is the result of incentive structure of the relationship between insurer and insured. Because after entering the contract, the farmer's incentive to take proper care of the crop diminishes, while the insurer has limited effective means to monitor the farmer.
3. *High administrative costs*. The cost of risk classification, monitoring systems for asymmetric information problems, acquiring the data needed to establish accurate premium rates and conducting claims adjustments are relatively high, especially, for a small policy.

Together, these effects create a wedge between the prices that farmers are willing to pay for catastrophic agricultural insurance and the prices that insurers are willing to accept.

Given the problems with some traditional crop insurance programs in developing countries, finding new solutions to help mitigate those problems has become critical. Index insurance products offer some potential in this regard (Skees et al. 1999). Index-based insurance is a way of protection against correlated risk such as extreme weather events and a promising means of overcoming moral hazard, adverse selection, cost of loss adjustment and fraud by linking insurance benefits to an objective index (like rainfall). Typically, the farmer is free to purchase as much cover as he or she wishes, and when the index is calculated at the end of the year, the payment received is a function of the amount of cover purchased rather the actual loss suffered. This makes claims payment very easy, as it does not require any claims validation beyond ensuring that the measurement of the index is correct. In effect, farmers do not need even to submit claims. At the end of the term, if the trigger has been met or exceeded they receive a payment. These characteristics make weather index insurance an ideal product to be sold by MFIs. So, the main differences of index insurance from traditional insurance are (1) indemnity payments are based on the value of underlying index highly correlated with farm-level yield; (2) underlying index is exogenous to the policyholder, but has a strong correlation with farm-level losses; (3) For index insurance, unlike to most insurance products, a precondition is that risk be spatially correlated. When yield losses are spatially correlated, index insurance contracts can be an effective alternative to traditional farm-level crop insurance.

B. Advantages and disadvantages of index insurance

Index-insurance sometimes offer high risk protection compared to traditional farm-level, multiple-peril crop insurance. Asymmetric information problems are much lower with index insurance because (1) a producer has little more information than the insurer regarding the index value; (2) producers are unable to influence the index value. This characteristic of index insurance means that there is less need for deductibles and copayments. Key advantages and challenges are summarized in Table 1.

Table 1. Advantages and Disadvantages of Index Insurance

Advantages	**Challenges**
Less moral hazard The indemnity does not depend on the individual producer's realized yield.	*Basis risk* Without sufficient correlation between the index and actual losses, index insurance is not an effective risk management tool.
Less adverse selection The indemnity is based on widely available information, so there are few informational asymmetries to be exploited	
Lower administrative costs Underwriting and inspections of individual	*Precise actuarial modeling* Insurers must understand the statistical

farms are not required.	properties of the underlying index
Standardized and transparent structure Contracts can be uniformly structured	*Education* Users must be able to assess whether index insurance will provide effective risk management
Availability and negotiability Contracts are standard and can be traded in secondary markets	*Market size* Market is in the stage of infancy and estimating demand for index insurance products is not well studied
Reinsurance function Index insurance can be used to transfer the risk of widely-spread correlated agricultural production losses more easily	*Microclimates* These production conditions make rainfall or area-yield index based contracts difficult for frequent and localized events
Versatility Index contracts can be easily bundled with other financial services, facilitating basis risk management.	*Forecasts* Asymmetric information about the likelihood of an event in the near future creates the potential for intertemporal adverse selection.

A major challenge in designing an index insurance product is minimizing basis risk. Basic risk is the potential mismatch between index-triggered payouts and actual losses.[1] It occurs when an insured has a loss and does not receive an insurance payment sufficient to cover the loss or when an insured has a loss and receives a payment that exceeds the amount of loss. On the other hand, an index-insurance policyholder can experience a yield or revenue loss and not receive indemnity because index-insurance payouts are triggered by exogenous random variable (such as area yields or weather events). It is also possible that the policyholder may receive an indemnity although he or she doesn't experience loss. The effectiveness of index insurance depends on how positively correlated farm yield losses are with the underlying index. The correlation will be highly positive if area is more homogenous and weather index represents the weather events the more closely.

However, index insurance may not work well for all agricultural producers due to the following reasons:

[1] Basis risk also exists with traditional farm-level, multiple-peril crop yield insurance. Typically, a very small sample size is used to develop estimates of the central tendency in farm-level yields and as a result, it generates large mistakes when estimating expected farm-level yield, thus making possible for farmers to receive insurance payments when yield losses have not occurred. Moreover, basis risk results from the estimate of realized yield. It is impossible to avoid errors on estimating the true realized yield. These errors can also result in under- and overpayments.

1. Many agricultural products are grown in microclimates where weather conditions differ largely within only a few miles (coffee, apples, cherries). Heterogeneous areas make basis risk as high as to make index insurance problematic.

2. Overfitting the data results in incorrect results. Trying to identify statistical relationship between the index and yield using limited amount of crop yield data can lead to wrong contract designs, because we can't assume that linear relationship can be used for designing contract for all farmers if data reveals linear relationship for a given sample. On the other hand, insurer should have better information that the insured. Usually farmers' weather forecasts are more highly accurate than insurance companies. If insurer doesn't know weather forecast as much as farmers do, adverse selection will render the index insurance product.

III. Designing a weather index insurance product

1. Characteristics of an index

The general property of index insurance is that it must be correlated with yield or revenue outcomes for farms across a large geographic area (Ruck 1999). On the other hand, the measurement risk for the index must be low (Ruck 1999). It means that index must have properties affecting the degree of confidence that index is believable, reliable and void of human manipulation. In general, a suitable index should meet the following criteria (World Bank):

- Observable and easily measurable
- Objective
- Transparent
- Independently verifiable
- Reportable in a timely manner (Turvey 2002)
- Stable and sustainable over time

2. Common Underlying Indexes

The units of measurement of weather indexes should convey meaningful information about the state of weather variable during the contract period and they often shaped by the needs and conventions of market participants.

A weather index can be constructed using any combination of measurable weather variables and any number of weather stations that best represent the risk of the agricultural end user. Common variables include temperature and rainfall, although transactions on snowfall, wind, sunshine hours, river flow, relative humidity, and storm/hurricane location and strength are also possible and are becoming more frequent. The index possibilities are limitless and flexible to match the exposure of the agricultural grower. Most weather indexes are based on temperature and precipitation.

1. Growing Degree Days

Growing Degree Days (GDDs) is a common index used in the agricultural sector, similar to HDDs (Heating Degree Days) and CDDs (Cooling Degree Days) in the energy sector. GDDs are a measurement of the growth and development of plants (both crops and weeds) and insects during a growing season. Organisms that cannot internally regulate their own temperature are dependent on the temperature of the environment to which they are exposed. Development of an organism does not occur unless the temperature is above a minimum threshold value, known as the base temperature, and a certain amount of heat is required for development to move from one stage to the next. The base temperature varies for different organisms and is determined through research and scientific considerations. A GDD is calculated by the following equation:

$$Daily\ GDD = max\ (0,\ T_{average} - L)$$

$$T_{average} = (T_{max} - T_{min})/2$$

where L is baseline temperature and $T_{average}$ is the daily mean temperature.

A GDD index x over an Nd day period is usually defined as the sum of the GDDs over all days during that period.

$$x = \sum_{i=1}^{N_d} GDD_i$$

Accumulated GDDs are a good proxy for establishing the development stages of a crop, weed or insect. Measuring the amount of heat accumulated over time is biologically more accurate than are calendar days (Neild and Newman 2005), and specific organisms, pest or plant, need different accumulated GDDs to reach different stages of development. In general, GDDS can be a good index for crop production.

2. *Event-based indexes*

Crop damage can be the result of specific or critical temperature events. In this case, event-based index can be used by a farmer to protect against crop failure risk.

Critical temperatures (for example, freezing conditions) causing crop damage may vary depending on the length of time that temperatures remain below freezing as well as on the variety, health and development of stage of a plant. Winter wheat yields at harvest, for example, depend to a great extent on how well the plants survive the winter hibernation period. Usually plants die when air temperature drops below – 16 deg C. A winterkill index, based on days when daily minimum temperature is less than -16^{o}C during the winter period from November to March, could be a good index.

3. *Rainfall/Drought Index*

The water requirements for crop development are usually met by natural rainfall, stored soil moisture from precipitation prior to the growing season and irrigation. For dry-land corn farming, 450 to 500mm or more rainfall during the growing season is required (Neild and Newman, 2005). Therefore, a deficit of rainfall below certain levels, in the absence of irrigation, can reduce yields. A simple cumulative rainfall index can be developed to suit grower's specific insurance requirements with regard to such decreases in rainfall and yield. The distribution of rainfall during the growing season or at specific stages of a plant's development is often more important than total rainfall, however, and customized indexes must be developed to capture this risk (Stoppa and Hess 2003).

3. Valuing Weather Risk

The premium of an index-based weather contract is determined actuarially by conducting a rigorous analysis of the historical weather to reveal the statistical properties and distribution of the defined weather index and, therefore, the payouts of the insurance or derivative contract. Such an analysis includes (1) cleaning and quality control of the data, that is, using statistical methods to in-fill missing data and/or to account for significant changes, if any, as a result of instrumentation or station location change; (2) checking the cleaned data for significant trends and detrending to current levels if appropriate; and (3) performing a statistical analysis on the cleaned and detrended data and/or a Monte Carlo simulation, using a model calibrated by the data, to determine the distribution of the defined weather index and the subsequent payouts of the contract. By determining the frequency and severity of weather events specified by the index, an appropriate premium can be calculated.

It should be noted that the premium charged by providers in the weather market may depend on several factors, such as the risk appetite, business imperatives and operational cost of insurers (Henderson et al. 2002).

To illustrate the pricing process, an index-based weather contract is structured as a call option. The payout, P, of the contract is determined by the following equation:

$$P=\min [\max(0, I-K) \times X, M]$$

where K is the strike, I is the index, X is the payout rate per unit index, and M is the limit of the contract.

$$Premium = E(P) + Risk\ Margin$$

$E(P)$ – expected loss of the contract or expected payout of the structure each year.

To determine risk taker's risk margin, Henderson et al. (2002) have suggested the *Sharpe ratio* and *Return on VaR*. They measure expected excess return in terms of some measure of risk and hence determine the "cost of risk" for the contract seller.

$$Sharpe\ ratio,\ \alpha=[Premium - E(P)]/\sigma(P)$$

$$Premium = E(P) + \alpha\sigma(P) \quad or$$

$$Return\ on\ VaR(99\%)^2,\ \beta = [Premium - E(P)]/[Var_{99}(P) - E(P)]$$

$$Premium = E(P) + \beta[Var_{99}(P) - E(P)]$$

The Sharpe Ratio uses standard deviation as the underlying measure of risk; therefore α represents the "cost of standard deviation" as determined by the seller's risk preferences. One of the benefits of relating risk to the standard deviation of payouts is that it constitutes an easy parameter for estimating; however, it is a symmetric measure of risk capturing the mean width of the payout distribution, and, for traditional risk exchange products, the payout distribution is often not symmetric but has a long tail. The Return on VaR method uses VaR(99%) as the underlying measure of risk and therefore β represents the "cost of VaR." The advantage of VaR is that it is computed from the loss side of the payout distribution, where loss is defined with respect to the expected payout E(P), and therefore captures the potential financial loss to the seller. Using the Return on VaR method is more appropriate for pricing structures that protect against low-frequency/high-severity risk, which have highly asymmetric payout distributions. VaR is a harder parameter to estimate, however, particularly for strike levels set far away from the mean, and it is usually established through Monte Carlo simulation. The worst-case recorded historically can often be used as a crosscheck for VaR. In both methods outlined above, α and β quantify the risk loading appropriate for the risk preferences of the provider.

In order to ensure that the insurance product has some relationship with the true risk exposure of the farmer, the limit of the insurance contract is negotiable with the farmer. However, it can't exceed a maximum estimated by the potential insured loss to the farmer.

4. Structure of index-based insurance contract

Index-based insurance contracts include the following information:

- defining the index;
- the buyer/seller information: names, crop and hectarage insured;

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[2] The 99th-percentile of the payouts or the 99 percent VaR represents the economic loss for the provider that is expected to be exceeded, with 1 percent probability, at the end of the calculation period of the contract.

- limit and tick-size;
- weather station and its location;
- the calculation period;
- the strike or deductible;
- the premium.

Figure 1 illustrates the sample weather insurance contract for winter wheat drought risk in Ukraine (Hess et al., 2005). Winter wheat yields at harvest depend to a great extent on how well the plant survives in air drought which describes conditions in which precipitation is low and high air temperature persists against a background of low relative air humidity. This leads to unfavorable conditions plant vegetation and drastically reduces the crop yields. The underlying drought index is Selyaninov Hydrothermal Ratio (SHR). For the vegetative growth period for winter wheat in Behtery, April 15 to June 30, the SHR is defined as follows:

$$SHR = \left(\sum_{15\,April-June} DailyRanfall\right) / \left(0.1 \times \sum_{15\,April-June} AverageDailyTemperature\right)$$

Conditions for obtaining the best harvest are when the SHR is between 1.0 and 1.4.

The payout of a SHR index insurance contract at Behtery is determined as follows:

$$Payout = min(max(0, K\text{-}SHR) \text{ x } X, M)$$

where K is the strike price, SHR is the SHR index measured during the calculation period, X is the payout rate and M is the limit of the contract.

Based on the estimations of Hess et al. (2005), a reasonable estimate for the risk loading factors α and β given prices in the weather market, are $\alpha=25\%$ and $\beta=5\%$. By simply taking the thirty years of payouts, the payout statistics for weather insurance contract with a strike level of SHR=0.4 can be calculated as follows: E(SHR)=UAH 70, σ(SHR)=UAH 220 and VaR97(SHR) = UAH 800. A first-order estimate of an appropriate premium to charge a farmer for an insurance contract with a strike level of SHR=0.4 at Behtery Weather Station, therefore, is between UAH 110 and 125 per hectare.

Figure 1. Sample Weather Index Contract

Buyer	Farmer A 222 Wheat Street, Behtery, Kherson, UA
Seller	ZZZ Insurance Company
Hectares of Winter Wheat	50 Hectares

Insured	
Calculation Period	April 15, 2008 to June 30, 2008
Location Behtery	Behtery Weather Station
Index, SHR	SHR = Index 1 / (Index 2 * Scaling Factor) Where: Index 1 = Cumulative Capped Daily Rainfall measured during the calculation period at Location. Measuring unit: mm Index 2 = Cumulative Daily Average Temperature measured during the Calculation Period at Location. Measuring Unit: Degrees Celsius Scaling Factor = 0.1
Capped Daily Rainfall	Capped Daily Rainfall = min (50, Daily Rainfall Total) Measuring unit: mm
Strike, K	0.4
Maximum payout, M	UAH 1000 per Hectar Insured
Settlement Calculation	1. If the Index SHR is greater than the Strike K no payment is made. 2. If the index SHR is less than or equal to the Strike K the Buyer receives a payout X per hectare insured from the Seller according to the following Settlement Calculation: If 0.36<max(K-SHR, 0)<0.41, X=UAH 500 If 0.31<max(K-SHR, 0)<0.36, X=UAH 600 If 0.26<max(K-SHR, 0)<0.31, X=UAH 700 If 0.21<max(K-SHR, 0)<0.26, X=UAH 800 If 0.16<max(K-SHR, 0)<0.21, X=UAH 900 If max(K-SHR, 0)<0.16, X=UAH 1000
Maximum Settlement	The maximum payment that can be made from the Seller to the Buyer is UAH 100,000.
Premium	The Buyer will pay the Seller a premium of UAH 12,000 for the weather protection outlined above.
Settlement Data	Ukrainian Hydrometeorological Centre, Kiev
Settlement Date	Within 45 days of the end of the Calculation Period.

IV. Conclusion

Developing index insurance products is extremely important to reduce the vulnerability of poor rural people to extreme weather events that can be devastating to agricultural productivity.

Given all the difficulties and challenges associated with index-based weather insurance and its poor record of sustainable success, it is reasonable to ask a question: Does index-based agricultural microinsurance make any sense as a development intervention? Before answering this question directly, we should review other actions which mitigate risk but are not insurance. The use of agricultural insurance as an *ex-post* (after the loss-causing event) risk management instrument should always be compared with reducing the risk *ex-ante*.

The most obvious way to reduce risk is to prevent it from happening in the first place. Vaccinating livestock, strengthening systems to prevent stock theft, planting more drought-resistant and pest-resistant crops – these are all ways to prevent the loss-making events from occurring.

Another way of mitigating risk, practiced as a matter of course by poor agricultural households all over the world, is for household members to share risk by pursuing multiple livelihoods, including off-farm activities, and pooling their income.

Non-insurance options can mitigate the effects of small losses, but for catastrophic losses, other than intervention by governments and aid agencies, there are few real substitutes for insurance. The mass of low income farmers live in regions subject to extreme weather conditions, from cyclones to droughts. Climate change exacerbates these extreme conditions, making life even riskier for poor people. Thus there remains a case to develop efficient index-based agricultural microinsurance, and it is worth considered where interventions to help this development can best be made.

Though insurers and reinsurers have been showing greater interest in covering weather risk in emerging markets, they face many challenges such as weak primary insurance markets and undeveloped regulatory and financial systems. However, development and implementation of this type of insurance can help the poor cope better when extreme weather hits and can open the door to other financial services, in particular credit.

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