AGRICULTURAL INSURANCE

BACKGROUND AND CONTEXT FOR CLIMATE ADAPTATION DISCUSSIONS

Jerry R. Skees, Barry J. Barnett, and Benjamin Collier[1]

GlobalAgRisk, Inc.
1008 S. Broadway
Lexington, KY 40504
859.489.6203
Jerry R. Skees, President

[1] Skees is the H.B. Price Professor of Risk and Policy in the Department of Agricultural Economics at the University of Kentucky, and president of GlobalAgRisk, Inc. Barnett is an associate professor in the Department of Agricultural Economics at Mississippi State University. Benjamin Collier is a project manager for GlobalAgRisk. The authors gratefully acknowledge the editorial assistance of Celeste Sullivan. This paper was developed for the OECD "Expert Workshop on Economic Aspects of Adaptation" held in Paris, France, April 7-8, 2008.

Table of Contents

Figures

Tables

Introduction[2]

This paper addresses the important question of whether agricultural insurance can facilitate farm household adaptation to climate change. The focus is on lower income countries and the emergence of index insurance as a new tool for delivering more cost-effective insurance to countries dominated by small farms. While agricultural insurance can provide needed funds when extreme weather events impact the livelihood of farmers, these funds will not necessarily be used for adaptation to climate change. Subsidizing agricultural insurance premiums may actually impede adaptation behavior.

Insurance is designed to protect against relatively infrequent loss events. It cannot protect against climate change impacts that are almost certain to occur. For example, since there is widespread agreement that climate change will cause higher temperatures in many areas and rising ocean levels, insurers will be reluctant to insure against these impacts—or they will do so only at prohibitively high cost. On the other hand, if climate change is causing more extreme weather events (i.e., increasing variability), agricultural insurance may be feasible.

Throughout the world, extreme weather events are a common cause of crop losses. Historic data for the United States show the following breakdown of crop losses by peril: excess moisture, 32 percent; droughts and heat, 31 percent; cold, frost, and freeze, 15 percent; hail, 9 percent; and other, 12 percent. Data for China show the following breakdown of crop losses by peril: droughts and heat, 49 percent; flood, 25 percent; hail, 10 percent; frost and freeze, 6 percent; and other, 10 percent[3]. In some regions, climate change is expected to increase the frequency of extreme rainfall and temperature events—the very events that currently create most agricultural losses. More troubling is that, for some regions, climate change is expected to generate increasingly hotter average temperatures or negative trends for rainfall. Trends in weather events may change the underlying climate to the extent that it is no longer feasible to grow the traditional crops in those regions.

The challenge of how to adapt to a changing climate has plagued societies throughout the history of humanity. Understanding more about climate change predications is at the core of developing appropriate public and private responses. By all counts, the need for informed public policy at many levels has intensified. At the global policy level, using insurance to encourage adaptation to climate change has been endorsed as one means for developed countries to assist lower income countries who are predicted to bear much of the brunt of climate change.[4]

Recent articles have highlighted how donors could support agricultural insurance for lower income countries in light of climate change (Linnerooth-Bayer et al., 2007). Many of these macro-oriented articles focus on creating global public support for *ex ante* financing of insurance to pay for what are expected to be greater losses in the future. While this is clearly an important consideration, it is equally important to understand more of the micro-level details regarding agricultural insurance and how insurance products are developed and priced. It is also critical to evaluate how the availability of subsidized insurance affects farmer decision making and thus, farmer adaptation to climate change.

[2] The authors developed this paper in conjunction with a World Bank Institute course, Weather Risk Management for Agriculture, which overlaps but is independent of the material presented in this paper (WBI/CRMG, 2008). The course for the World Bank Institute maintains a practitioner focus on the steps to implementing an index insurance program. For more information on the course, please contact the World Bank Institute.

[3] Data for the United States come from the Risk Management Agency. Data for China come from the China Yearbook and Belete et al., 2007.

[4] See Article 4.8 of the United Nations Framework Convention on Climate Change (UNFCCC).

This paper is targeted at reviewing developments in agricultural insurance in lower income countries and increasing the understanding of how subsidized insurance, unless very carefully constructed, may create disincentives for farmer adaptation to climate change.[5]

The paper begins with a brief discussion of how insurance, and particularly subsidized insurance, can affect farmer decision making. These effects on micro-level decisions have important macro-level implications. Next, several challenges associated with providing agricultural insurance are described followed by a discussion of factors that influence the price of insurance. A review of two different types of agricultural insurance products follows. This review illustrates how different agricultural insurance products are designed, including the underwriting and actuarial concerns that must be considered to develop sustainable products. It also lays the foundation for understanding how mistakes in estimating the loss function can impact the actuarial performance of an insurance product.

Better understanding the cost of providing different types of insurance products helps to illustrate why multiple peril crop insurance is too costly for lower income countries that are dominated by small farms. This conclusion has spawned a host of pilot programs using index insurance products that are believed to be more suitable for countries with small farms. The paper briefly describes some ongoing index insurance pilot programs and lists all of the pilots of which the authors are aware. While index insurance products have many advantages over multiple peril crop insurance, they have one major disadvantage: the policyholder remains exposed to basis risk—a farmer may have a crop failure when the proxy for loss (e.g., the weather event) does not trigger a payment. Experience with index insurance products remains relatively limited and their long-term viability remains unproven.

Finally, we return to the issue of climate change and the conditions for using agricultural insurance to facilitate adaptation to climate change. A clear message emerges: only under special circumstances can subsidized agricultural insurance be compatible with the goal of adaptation to climate change.

Farmer Portfolios and Insurance

Households manage portfolios of assets from which they hope to generate net returns. For rural farm households in lower income countries, those assets have often been acquired at very high opportunity cost in the form of foregone consumption. While some farmers invest in financial assets such as savings accounts, these products are generally not available in rural areas of lower income countries (McPeak and Barrett, 2001; Dercon, 1998; Besley, 1995). Instead, farmers tend to invest in assets such as livestock, farm and household tools, equipment, irrigation canals, fertilizer, perennial crops, and the human capital of family members (e.g., education, immunizations, etc.).

Consider a farmer who manages a portfolio of n assets. Each asset A_i ($i = 1, 2, \ldots n$) generates a stochastic periodic net return r_i such that the net return on the entire portfolio of assets R is

$$R = \sum_{i=1}^{n} w_i r_i$$

where w_i is the proportion of the total value of the portfolio that is invested in A_i and $\sum_{i=1}^{n} w_i = 1$.

[5] While this paper focuses on agricultural insurance, the conceptual arguments presented would also apply to many other forms of weather insurance (e.g., property and casualty insurance for flooding or damage caused by cyclones).

The risk of the portfolio (measured as the variance of returns) is calculated as $\sigma_R^2 = \sum_{j=1}^{n}\sum_{k=1}^{n} w_j w_k \sigma_{jk}$

> where σ_{jk} is the variance in returns on the single asset when $j = k$ and the pairwise covariance in returns when $j \neq k$ with $\sum_{j=1}^{n} w_j = 1$ and $\sum_{k=1}^{n} w_k = 1$.

The farmer maximizes a generalized expected utility function defined over the distribution of R and subject to relevant constraints, with $\frac{\partial E(U)}{\partial E(R)} > 0$ and $\frac{\partial E(U)}{\partial \sigma_R^2} < 0$.[6]

Thus, expected utility is increasing in expected returns and decreasing in the variability of returns. The latter implies that the farmer is risk-averse.

If the farmer purchases insurance, the insurance policy is simply another asset in the portfolio.[7] Insurance purchasing will typically decrease both $E(R)$ and σ_R^2. $E(R)$ will decrease because the insurance premium will not be actuarially fair—that is, $E(r_{insurance}) < 0$. As described in the following section, the insurer will load the insurance premium to cover various expenses (information collection and processing, delivery, loss adjustment, risk financing, etc.) and to provide a competitive return on equity. The variability of net returns σ_R^2 will decrease because, by design, returns from the insurance policy are negatively correlated with returns from at least one other asset in the portfolio. Only farmers who are risk-averse (i.e., utility is decreasing in σ_R^2) would purchase typical insurance policies for which $E(r_{insurance}) < 0$.

For risk-averse farmers, the insurance purchase decision involves a tradeoff between the utility generated from a reduction in σ_R^2 and the disutility generated from a reduction in $E(R)$, with more (less) risk-averse farmers being more (less) willing to pay insurance premiums in exchange for reduced risk. This tradeoff implies that, in some cases, the risk associated with certain assets will be so high that the farmer will not invest in those assets unless some mechanism exists (such as insurance) to transfer the risk exposure to others. The risk may be that returns from the asset are extremely variable and insufficient diversification opportunities exist (or those opportunities involve excessive opportunity costs). Alternatively, for an asset that would constitute a major portion of the overall portfolio, the risk may be that the asset itself may be damaged or destroyed thus eliminating its ability to generate future returns. It is in this respect, that the availability of insurance can stimulate investment and economic growth. Risk-averse farmers, that would otherwise be reluctant to invest in assets or engage in livelihood strategies that involve higher expected return but also greater risk exposure, are more

---

[6] For ease of exposition, a generalized conceptual model is presented here rather than a model that specifies functional relationships. Also, the model is static whereas a more mathematically complex temporal model would allow for investment in, and liquidation of, assets. The generalized static model is sufficient to motivate a discussion of how insurance purchasing affects household behavior. More detailed and complex expected utility models of rural household decision making under conditions of risk can be found in Rosenzweig and Binswanger (1993), Rosenzweig and Wolpin (1993), and deJanvry, Fafchamps, and Sadoulet (1991). These works demonstrate that these principles apply even among poor farmers in lower income countries.

[7] The insurance may protect against decreased revenue (e.g., crop yield or revenue insurance) or increased expenses (e.g., health insurance) associated with one or more assets in the portfolio. Alternatively, it may protect against the actual loss of one or more assets (e.g., property or life insurance).

likely to consider such alternatives if the risk exposure can be transferred to other parties via insurance (Barnett, Barrett, and Skees, n.d.).

This reasoning is sometimes used to argue that insurance products—in particular, insurance against catastrophic risks—should be subsidized. By lowering the cost of insurance, more farmers would purchase insurance and invest in higher risk, higher return assets. But, of course, the increased investment will occur only in those sectors for which the subsidized insurance is being offered. Capital will flow out from other sectors into the sector for which subsidized insurance is being offered. Those who propose insurance subsidies rarely consider the opportunity cost of both the funds used to pay the subsidies and the capital flows that are diverted from other uses into the sector for which subsidized insurance is available. In lower income countries, these opportunity costs are likely quite high.

Subsidized insurance can cause economic inefficiencies by encouraging farmers to invest scarce resources into production assets that are very risky, in part because they are not well-suited to local market or environmental conditions. For example, in developed countries, subsidized insurance encourages households to build expensive homes on beachfront property or in floodplains (Mileti, 1999). Subsidized insurance also encourages farmers to produce water-dependent crops in areas that suffer frequent droughts (Skees, 2001).[8]

In the same way, subsidized insurance can also create a disincentive for farmers to adapt to changing climatic conditions. Insurance prices provide a signal to farm household decision makers about the risk associated with engaging in particular livelihood strategies (e.g., cropping choices) or investing in particular assets. If experts believe that climate change has increased the risk associated with certain livelihood strategies or assets, farm households will receive this signal in the form of higher insurance premiums. But premium subsidies distort this price signal and thus retard incentives for farm households to adapt to changing climatic conditions. In this way, premium subsidies may actually increase the vulnerability of farm households to the risks associated with climate change.

The point is not necessarily that insurance should never be subsidized. Rather, the point is that when insuring against catastrophic climatic events, any subsidies should be carefully constructed to reduce the potential for perverse behavioral incentives. This is discussed further below.

Problems and Challenges of Offering Agricultural Insurance

Agricultural insurance is among the most difficult insurance to develop. As this section explains, agricultural insurance represents a special class of insurance since the risks are correlated. In the classic insurance literature (Rejda, 2001), a pre-condition for insurance is that risk should be independent. Additionally, significant information asymmetry problems plague agricultural insurance. Farmers will always know that more than insurers about their yield potential.

Correlated Risk and Agricultural Insurance

The history of agricultural insurance has been largely about attempting to affordably manage the risk of spatially correlated losses (i.e., many people in the same region experience losses at the same time).

[8] It is important to note that insurance subsidies can also contribute to environmental degradation. For example, agricultural insurance subsidies will create incentives for farmers to increasingly produce on marginal lands. In many cases, these marginal lands will require larger fertilizer applications and be more prone to erosion (Wu, 1999). Similarly, increased development pressure along shorelines or floodplains contributes to erosion and other environmental problems (Dean, 1999).

Many weather events (e.g., drought, torrential rain, cyclone, excessively high or low temperatures, etc.) can create correlated losses in agricultural production.

Managing correlated risk requires special arrangements for insurers. Insurers collect regular premiums from the insured but may experience very high indemnities in some years and very low indemnities in others. Therefore, insurers employ several techniques to smooth their losses over time (e.g., reserving funds and reinsurance). Governments often provide reinsurance services with favorable terms to agricultural insurers, arguing that the large financial exposure that is created when insuring correlated losses creates a market failure, requiring government support. These reinsurance services help protect the insurers against correlated risks (Miranda and Glauber, 1997).

Asymmetric Information Problems Associated with Insuring Agricultural Production

There are two key components to designing any agricultural insurance product. First, it must be possible to estimate the risk being assumed by the insurer. Second, to the extent possible, the product must be designed so that it will not be susceptible to abuse by the insured. The costs associated with monitoring and administering agricultural insurance must also be determined.

Insurance suffers from many of the classic principal/agent problems that plague markets characterized by information asymmetry. An insurer must know a great deal about the characteristics of the risk being assumed. Yet, farmers will always know more about their management strategies and yield potential than will an insurer. This asymmetric information is the core reason that adverse selection and moral hazard problems are pervasive for most crop insurance products.

Adverse selection is created by hidden information. The insurer cannot accurately assess each individual's risk exposure since it does not know the management, soils, and other special conditions that will affect crop yields. The insured knows much more. Therefore, many high risk individuals will be offered insurance coverage at premium rates that are too low and many low risk individuals will be charged premium rates that are too high. When this occurs, the pool of those actually purchasing insurance will disproportionately comprise those who have the highest risk—those with lower risk will generally not purchase the insurance. Such an adversely selected insurance pool will doom the insurance product to failure. Many countries choose to address this problem by adding premium subsidies. While this does attract the lower risk farmers back into the insurance pool, the premium subsidies are applied to all insurance policies. The subsidy is generally a percentage of the total premium which means that high risk individuals actually receive most of the subsidy because they have higher premiums.

Moral hazard is created by hidden actions. Farmers who purchase crop insurance may change their behavior after the purchase so as to create more risks than the insurer provided for in the premium rates. For example, if a farmer has crop insurance they may be more willing to take the risks associated with an emerging pest problem (i.e., they may chose not to spray for the pest because they have insurance). Moral hazard can also become fraud if the insureds misrepresent their losses.

Pricing of Agricultural Insurance

Examining the elements of agricultural insurance pricing further highlights the difficulty associated with underwriting this form of insurance. The following equation gives a breakdown of the costs that factor into the price of insurance:

Price of Insurance = Cost of the Risk + Administrative Costs + Cost of Ready Access to Capital

Cost of the Risk

Estimating the "pure" risk is the beginning point for pricing any insurance contract. If an ongoing insurance product exists, actuaries use historical loss cost (indemnities divided by sum insured) as the primary source of information for estimating the pure risk. For new insurance products pure risk is estimated using available data to simulate expected loss cost. In either case, sufficient quality data are the key to making these calculations.

For new insurance products, actuaries use data regarding frequency and severity to develop a probability density function of simulated losses. From the probability density function of simulated losses, actuaries can estimate the pure risk (expected loss cost) of the insurance contract.

For example, suppose an insurance product that pays an indemnity n whenever losses l exceed the deductible q. The expected indemnity is $E(n(l \mid q)) = \int_0^{\omega} \max(l - q, 0) h(l) dl$

where ω is the sum insured (the maximum possible indemnity) and $h(l)$ is the probability density function of losses.

The pure risk measured as the expected loss cost is then $\frac{E(n(l \mid q))}{\omega}$.

If the pure risk were equal to 5 percent, this would indicate that over time the insurer expects indemnities to average 5 percent of the sum insured on the insurance policies.

Ambiguity loads are also common when insuring against extreme weather risk events. Even if major loss events have not occurred in recent memory, insurers are aware that such events are possible. They attempt to determine the maximum probable loss that they could incur with any given insurance policy. Extreme events are always possible. The probability of such events must be considered when establishing premiums. Changing trends, such as decreasing rainfall, also contribute to ambiguity and can significantly increase premium rates.

Catastrophic loads must also be included in the cost of insuring against correlated risk. Catastrophic loads are based on the recognition that substantial losses may occur early in the life of the insurance program before significant reserving funds are developed.

Administrative Costs

Information costs to control adverse selection can be significant. To the extent that the insurer attempts to underwrite individual or farmer-level risks, it will be costly to obtain the data needed. For example, if an insurer is underwriting traditional multiple peril crop insurance, it would be important to know the inputs used for the crop (e.g., amount of fertilizer, seed varieties, soil types, etc. as well as the production experience and abilities of the farmer).

Monitoring to control moral hazard adds to the price of insurance as well. If the insurance is for multiple risks, it will be important to know that the farmer is using standard best management practices. If management actions taken by the insured farmer can influence the probability or severity of losses, some type of monitoring system will be required.

Loss adjustment is an important insurance activity that can be costly and imprecise. For insurance against correlated weather events, many policyholders are likely to require loss adjustment at the same time when an extreme event occurs. This can put a serious strain on the resources of an insurance company. Furthermore, estimating losses for crops can be quite difficult, especially if the crop insurance covers multiple perils. For example, loss adjusters may be unable to determine if a loss was due to bad weather or bad management.

Delivery costs also add to the price of insurance. It is expensive to send sales agents to the countryside to visit individual farmers. This is particularly true in countries where individuals have little prior experience with any form of insurance. It may take multiple visits to convince a farmer decision maker to purchase the insurance. Of course, if losses occur, the insurer must also bear the expense of sending loss adjusters to the countryside.

Cost of Ready Access to Capital

The cost of ready access to capital to pay for all losses adds yet more to the price of agricultural insurance products. Given that an extreme event can occur in the very first year of the insurance offering, the insurer must have the capacity to pay for losses that may exceed annual premiums by several times. They do this by accessing international markets that insure the insurance companies—"reinsurers." Maintaining ready access to capital comes at high opportunity costs for insurers as these funds could be used to expand business; however, maintaining reserving funds is a necessity as insurers underwriting correlated risk will inevitably experience losses that far exceed insurance premiums in some years.

Two Types of Agricultural Insurance Products: Multiple Peril Crop Insurance (MPCI) and Index Insurance[9]

Multiple peril crop insurance (MPCI) is also called "yield-based crop insurance." Insured yield (e.g., tons/ha) is established as a percentage (typically between 50 and 70 percent) of the historical average yield for the insured plot. If the realized yield is less than the insured yield, an indemnity is paid based on the difference between the actual yield and the insured yield (Skees and Barnett, 2004). As it is generally difficult to determine the exact cause of loss, MPCI typically protects against many different causes of yield loss. When insuring for multiple perils, it is very difficult to first identify the "set of perils" that may have created the losses and then perform a loss assessment that attempts to separate the actual loss by peril. It is often difficult to tell whether the loss was due to an insured event (e.g., drought) or to poor management practices

Multiple peril crop insurance was first developed by the U.S. government (Barnett, 2000). The yield-based approach to loss measurement is attractive to farmers and to financing institutions lending to farmers as it is designed to capture all causes of yield losses. MPCI is most beneficial when the damage to crops is complex, for example, when many perils interact, such as rainfall and disease. Similarly, drought gradually develops over a crop season and many times is compounded by extreme heat.

Cost of MPCI

Despite the many advantages of MPCI, individual farmer MPCI has proven to be highly problematic for insurers. Key difficulties associated with MPCI have been extensively documented and the cost components can be summarized as follows:

- Because it protects against multiple perils, the cost of risk for MPCI is quite high.
- MPCI tends to be highly susceptible to adverse selection. A great deal of information is required to classify the risk exposure of potential policyholders.

[9] Named Peril such as crop-hail insurance is another common form of agricultural insurance that is not developed in this paper as these policies have limited application to the problems created by climate change.

- MPCI tends to be highly susceptible to moral hazard. It is practically impossible for the insurer to monitor the behavior of all policyholders.
- Loss adjustment is difficult and costly. Highly skilled loss adjusters must try to determine whether the yield loss was due to an insured peril and, if so, the magnitude of the loss.
- Delivery costs are quite high. The farmer must provide historical data on hectares planted and tons produced. The sales agent must be able to verify that these data are based on objective third-party sources.
- Among the perils that are typically covered by MPCI are spatially correlated perils such as drought. Thus, MPCI has high costs associated with providing sufficient access to capital.

One can see why the cost of providing MPCI is very expensive. As a result, most MPCI programs have large premium and/or administrative subsidies paid by the government (Glauber, 2004; Glauber and Collins, 2002). An additional issue with MPCI is that the information, monitoring, loss adjustment, delivery, and administrative costs generally do not vary much with the size of the policy. Thus, MPCI is clearly better suited for countries characterized by larger farms. Yet even in those countries, MPCI is generally not financially sustainable without large government subsidies. For this reason, MPCI is not a viable option for most lower income countries that are dominated by small farms (Skees and Collier, 2007).

Experience with MPCI

Hazell (1992) documented the experience with government-supported MPCI programs. He created a simple ratio to give a clear indication of how much support was being provided by governments. His logic was simple: for a program to be self-supporting and sustainable, the premiums collected should exceed the sum of indemnities paid and administrative costs over the long run. Thus, for a self-supporting program

$$\frac{I + A}{P} < 1.00$$

where I is indemnities, A is administrative costs, and P is premiums paid by farmers.

If the program is not self-supporting, the extent to which the ratio exceeds 1.00 is a measure of government support.

Table 1 presents these data for 7 countries from the 1970s and 1980s. The sustainability ratio is greater than 2 for every country. If one ignores administrative costs, only Japan for the period 1985–90 had a ratio that suggests premiums are greater than indemnities. However, to achieve this level of performance with Japan's small farm structure, administrative costs were more than 3.5 times greater than premiums. This is extreme, and clearly raises questions about the extent to which these costs are offset by social benefits. As discussed above, if countries are not willing to incur the needed cost to control problems of adverse selection and moral hazard, Table 1 suggests that they will almost certainly pay for these problems with poor actuarial performance, or as in the case of the United States, by adding premium subsidies in an attempt to mask the poor actuarial performance.

Table 1 Financial Performance of Crop Insurance in Seven Countries

Country	Time Period	I/P	A/P	(I + A)/P
Brazil	1975–81	4.29	0.28	4.57
Costa Rica	1970–89	2.26	0.54	2.80
India	1985–89	5.11	n/a	n/a
Japan	1947–77	1.48	1.17	2.60
Japan	1985–89	0.99	3.57	4.56
Mexico	1980–89	3.18	0.47	3.65
Philippines	1981–89	3.94	1.80	5.74
United States	1980–89	1.87	0.55	2.42

Source: Hazell, 1992

Brazil has now discontinued their crop insurance program and Mexico totally revamped their program in 1990. The current Mexican program still has a ratio that exceeds 2. The Philippine program has been greatly reduced in size. The ratio of indemnities to premiums of the Indian area-yield program remains very high at about 3 to 4 (depending on the number of years used). The current measure of this ratio for the U.S. Federal Crop Insurance Program (FCIP) is even greater than the period reflected in Table 1 with a value that exceeds 3.5.

Index Insurance

Index insurance uses an objective third-party measure as a proxy for individual losses (Collier, Murphy, and Skees, 2008; Collier and Skees, 2008; Barnett and Mahul, 2007; Hazell and Skees, 2006). To be effective the indexed measure must be highly correlated with realized losses. The insured must have an insurable interest to purchase index insurance. There are several examples of index insurance. The two most common for crop yields are area-yield index insurance and weather index insurance.

Area-Yield Index Insurance. The indemnity is based on the realized average yield of an area such as a county or district and is paid when the realized yield for the area in a given season is below a certain percentage of the expected area yield (regardless of the actual yield on a policyholder's farm). This type of index insurance requires historical area-yield data.

Weather Index Insurance. The indemnity is based on measurements of a specific weather parameter measured over a pre-specified period of time at a particular weather station. The insurance can be structured to protect against index values that are either so high or so low that they are expected to cause crop losses. For example, the insurance can be structured to protect against either too much or too little rainfall. An indemnity is paid whenever the realized value of the index exceeds a pre-specified threshold (e.g., when protecting against too much rainfall) or when the index is less than the threshold (e.g., when protecting against too little rainfall). The indemnity payment is calculated based on a pre-agreed sum insured per unit deviation of the realized index value from the threshold value. An advantage of weather index insurance over area-yield index insurance is that many lower income countries have meteorological bureaus that collect and maintain weather data, whereas historical area-yield data is often difficult to obtain.

It is useful to note that area-yield index insurance is a form of multiple peril crop insurance since estimates of area yields involve the realized-yield outcome from a full growing season that will involve multiple weather events. By contrast, weather index insurance is generally written on a single named peril. It is atypical to find weather index insurance that is written on more than one peril. Nonetheless, because index insurance indemnities are based on the realized value of the index rather than farm-level losses, the costs of providing index insurance are much less than farm-level MPCI[10].

Cost of Index Insurance

In general, index insurance (either area-yield index insurance or weather index insurance) has the following advantages relative to MPCI:

- Since indemnities are based on the realized value of the index rather than farm-level losses, there is no need to collect farm-level information. Insurers no longer have to control for adverse selection because the risk exposure of individual clients does not have to be identified. Furthermore, there is little reason to believe that the farmer has any better information than the insurer regarding the risk of the underlying index (e.g., area yields, rainfall, or temperature).
- There is no need to monitor for moral hazard because the farmer cannot influence the likelihood or magnitude of an indemnity.
- Delivery costs are reduced. The enrollment process is less complex since there is no need to establish and verify an average farm-level yield. As a result, the product can be sold by less skilled personnel.
- There is no need for farm-level loss adjustment.

These benefits greatly reduce the cost of providing index insurance relative to the cost of MPCI and create opportunities to insure crop or livestock enterprises which might otherwise be uninsurable.

The most important disadvantage of index insurance is *basis risk*, which is variability in the relationship between the value of the index and the losses experienced on the farm. With index insurance it is possible for the farmer to experience a loss and yet not receive an indemnity, or the farmer may receive an indemnity and not experience a loss. These events are possible because the indemnity is based solely on the realized value of the index. If the index and farm-level yields are highly correlated, basis risk should be very small. If the index and farm-level yields are not highly correlated, basis risk may be quite high, suggesting that the index insurance may not be appropriate for that farm. Basis risk occurs due to spatial variation in weather variables (particularly where there are local microclimates) as well as differences in management practices, soil quality, or crop varieties.

Careful insurance product design can reduce (but not eliminate) basis risk. In particular, it is important that the index reflect spatially correlated loss events such as drought or extreme temperatures. Index insurance should be designed to ensure that farmers will receive some payments during the very worst years. Localized perils such as hail or frost (which may also be affected by topography and microclimates) are not well suited to index insurance.

[10] In any discussion of area-yield index insurance it is important to clarify a common point of confusion. With area-yield index insurance, area-yield data are used both to establish the yield guarantee and to adjust losses. A common mistake in MPCI insurance programs is to use area average yields to establish the yield guarantee but then adjust losses based on farm-level yields. This practice is inherently flawed since it effectively provides more (less) insurance protection to those whose expected yields are less (greater) than the area average yield. The result will be even greater adverse selection where those with the lowest (highest) expected yields will be most (least) inclined to purchase insurance (Skees and Reed, 1986).

In practice, it is often more feasible to develop weather index insurance rather than area-yield index insurance. This is because the meteorological bureaus in many countries have long time-series of accurate, consistent, and secure weather data for various weather stations across the country. It is far less common to find long time-series of accurate, consistent, and secure measures of crop yield data.

Experience with Index Insurance Programs

The origin of using an index for insurance was India. Chakravati (1920) was working on this problem in the context of a country that is dominated by small farms as early as 1920. India has the most extensive area-yield index insurance program in the world when comparing number of farmers insured (over 18 million farmers purchased the basic area-yield insurance in 2006). Actuarial experience has been poor due largely to very limited attempts to actually price the insurance properly. The U.S. FCIP has also offered an area-yield index insurance product known as the Group Risk Plan (GRP) since 1993. This program is priced using actuarial principles but, like other products in the U.S. FCIP, it is heavily subsidized by the federal government (Skees, Black and Barnett, 1997).

More weather index insurance policies are sold in India than in any other country; though many other countries have weather index insurance programs that are either under development or in pilot-testing (see Table 2). Weather index insurance was first sold in India in 2003 by the insurance company ICICI Lombard in partnership with the microfinance institution BASIX (Collier, Murphy, and Skees, 2008; Barnett and Mahul, 2007; Giné, Townsend, and Vickery, 2007a; Giné, Townsend, and Vickery, 2007b; Manuamorn, 2007; Hess et al., 2005; Lilleor et al., 2005; Hess, 2003). In 2004 other insurers, including the parastatal insurance company Agriculture Insurance Company of India (AICI), entered the market. In 2005, 250,000 rainfall insurance contracts were sold to farmers in India with AICI selling roughly half the policies (Ibarra and Syroka, 2006). In 2007, AICI sold 675,000 weather insurance policies.[11] While this is the largest weather index insurance program in the world, it is important to remember that there are an estimated 120 million farmers in India.

Despite the progress made with index insurance, at this stage, there is insufficient empirical evidence to reach definitive conclusions regarding the actuarial performance of these weather index insurance pilots. Skees (2008) provides a more detailed overview and critical review of the challenges associated with providing index insurance in lower income countries.

[11] Personal communication between Jerry Skees and Kolli Rao of AICI

Table 2 Index Insurance Pilots

Country	Risk Event	Contract Structure	Index Measure	Target User	Status	Source
Bangladesh	Drought	Index insurance linked to lending	Rainfall	Smallholder rice farmers	In development; pilot launch planned for 2008	Barnett and Mahul 2007
Caribbean Catastrophe Risk Insurance Facility	Hurricanes and earthquakes	Index insurance contracts with risk pooling	Indexed data from NOAA and USGS	Caribbean country governments	Implemented in 2007	Barnett and Mahul 2007 Isom 2007
China	Low, intermittent rainfall	Index insurance	Rainfall and storm day count	Smallholder watermelon farmers	Implemented June, 2007 in Shanghai only; includes a 40% premium subsidy	Barnett and Mahul 2007
Ethiopia	Drought	Index insurance	Rainfall	WFP operations in Ethiopia	USD 7 million insured for 2006; policy not renewed for 2007 due to lack of donor support	Skees et al. 2006 Syroka and Wilcox 2006
	Drought	Index insurance	Rainfall	Smallholder farmers	2006 pilot; currently closed due to limited sales	Barnett, Barret, and Skees forthcoming
	Drought	Weather derivative	Satellite and weather data	NGO	Implemented in 2007	Swiss Re 2007
Honduras	Drought		Rainfall		In development	Syroka 2007
India	Drought and flood	Index insurance linked to lending; offered directly to farmers	Rainfall	Smallholder farmers	Began with pilot in 2003; index insurance products now offered by private sector and government	Monuamorn 2007 Ibarra and Syroka 2006
Kazakhstan	Drought	Index insurance linked to MPCI program	Rainfall	Medium and large farms	In development	Barnett and Mahul 2007
Kenya	Drought	Weather derivative	Satellite and weather data	NGO	Implemented in 2007	O'Hearne 2007
Mali	Drought	Weather derivative	Satellite and weather data	NGO	Implemented in 2007	Swiss Re 2007
Malawi	Drought	Index insurance linked to lending	Rainfall	Groundnut farmers who are members of NASFAM	Pilot began in 2005; 2500 policies sold in 2006 pilot season; $7000 in premium volume	Alderman and Haque 2007 Leftley and Mapfumo 2006
Mexico	Natural disasters impacting smallholder farmers, primarily drought	Index insurance	Rainfall, windspeed, and temperature	State governments for disaster relief; Supports the FONDEN program	Pilot began in 2002; available in 26 of 32 states; currently 28% (2.3 million ha) of dryland cropland is covered	Agroasemex 2006a Skees et al. 2006
	Major earthquakes	Index-linked CAT bond and index insurance contracts	Richter scale readings	Mexican government to support FONDEN	Introduced in 2006; CAT bond provides up to USD 160 million; index insurance coverage up to USD 290 million	Wenner 2007 Cárdenas 2006

Table 2 Index Insurance Pilots *(Continued)*

Country	Risk Event	Contract Structure	Index Measure	Target User	Status	Source
Mexico *(Continued)*	Drought affecting livestock	Index insurance	Normalized Difference Vegetation Index	Livestock breeders	Launched in 2007, sum insured USD 22.5 million across 7 states, insured 913,000 cattle	Agroasemex 2006b
	Insufficient irrigation supply	Index insurance	Reservoir levels	Water user groups in the Rio Mayo area	Proposed	Skees and Leiva 2005
Mongolia	Large livestock losses due to severe weather	Index insurance with direct sales to herders	Area livestock mortality rate	Nomadic herders	Second pilot sales season of pilot completed in 2007, 14% participation	Mahul and Skees 2005 Skees and Enkh-Amgalan 2002
Morocco	Drought	Index insurance	Rainfall	Smallholder farmers	No interest from market due to declining trend in rainfall	Barnett and Mahul 2007 Skees et al. 2001 Stoppa and Hess 2003
Nicaragua	Drought and excess rain during	Index insurance	Rainfall	Groundnut farmers	Launched in 2006	Barnett and Mahul 2007 Syroka 2007
Peru	Flooding, torrential rainfall from El Niño	Index insurance	ENSO anomalies in Pacific Ocean	Rural financial institutions	Proposed	USAID 2006 Skees, Hartell, and Murphy 2007
	Drought	Index insurance linked to lending	Area-yield production index	Cotton farmers	Proposed	Carter, Boucher, and Trivelli 2007
Senegal	Drought	Index insurance linked to area-yield insurance	Rainfall and crop yield	Smallholder farmers	Proposed	Barnett and Mahul 2007 Swiss Re 2007
Tanzania	Drought	Index insurance linked to lending	Rainfall	Smallholder maize farmers	Pilot implementation in 2007	Barnett and Mahul 2007 Swiss Re 2007
Thailand	Drought	Index insurance linked to lending	Rainfall	Smallholder farmers	Pilot implementation in 2007	Barnett and Mahul 2007 Manuamorn 2006
Ukraine	Drought	Index insurance	Rainfall	Smallholders	Implemented in 2005; currently closed due to limited sales	Barnett and Mahul 2007 Skees, Hess, and Ibarra 2002
Vietnam	Flooding during rice harvest	Index insurance linked to lending	River level	The state agricultural bank and, ultimately, smallholder rice farmers	In development; a draft business interruption insurance contract is being considered by the state agricultural bank	Skees, Hartell, and Murphy 2007

Source: Authors (An earlier version published in Barnett, Barrett, and Skees, n.d.)

Conclusions on the Costs Associated with Basic Crop Insurance Products

Table 3 presents several generalizations about the relative costs of MPCI and index insurance. The generalizations are obviously conditioned on a number of assumptions. First, it is assumed that average farm size is small in most lower income countries. Second, it is assumed that weather index insurance is written on a major weather event that causes correlated losses (e.g., drought or excess rainfall). Third, it is assumed that the infrastructure for writing weather index insurance is in place. This may be a poor assumption if significantly more weather stations are needed to offer the weather index insurance and the cost of maintaining these new weather stations must be covered by the insurance program. Given the public good nature of weather data, it is difficult to assess these costs.

Table 3 Relative Cost Positions of Basic Crop Insurance Products

	Cost of Pure Risk	Administrative Costs	Cost of Capital
Farm-Level MPCI	High (Covers multiple perils)	High (Due to high information, monitoring, and farm-level loss adjustment costs)	High
Weather Index Insurance	Moderate (Covers a single peril)	Low (No need to collect farm-level risk information, monitor farmer behavior, or conduct farm-level loss adjustment)	High

Source: Authors

In conclusion, weather index insurance is easier to develop and less costly to operate than MPCI, in particular in countries in the world where farm yield data would be largely unavailable. The information, monitoring, loss adjustment, delivery, and administrative costs of MPCI are very high—especially if the insurer is selling to smallholders. Thus, despite the associated basis risk, in recent years the majority of attempts to develop agricultural insurance for lower income countries have focused on weather index insurance. For this reason, as we move into a discussion on using agricultural insurance to facilitate climate change adaptation in lower income countries, we focus on weather index insurance as the instrument of choice.

Climate Change and Insurance

Having described the components of insurance pricing we now return to our original challenge—whether agricultural insurance can be used to help farmers in lower income countries adapt to climate change. First, we describe the effects of climate change on the price of insurance with a focus on addressing correlated risk at prices affordable to farmers. Then, we discuss broader government and donor interventions intended to help farmers adapt to climate change and how index insurance might be used most effectively in this context.

The Effects of Climate Change Are Largely Uncertain

Climate describes the combination of weather patterns for a region over a long period of time (e.g., 30 years). Since the beginning of agriculture, farmers have been forced to adapt to changing climate conditions. Recently, however, a growing majority of scientists have concluded that anthropogenic contributions to greenhouse gases are leading to a new type of climate change that results in long-term consequences on a global level (e.g., Lobell et al., 2008; Bindoff et al., 2007; Carter et al., 2006).

Models predicting the extent of climate change differ dramatically, but tend to indicate that it is likely to affect different regions differently. In general, models predict temperatures will increase and rainfall will become erratic with some regions experiencing increasing intensity in rainfall (Lobell et al., 2008; Carter et al., 2006). For example, Lobell et al. (2008) examine 20 global circulation models for 12 food-insecure regions (e.g., Southern Africa, Southeast Asia) and find differing, sometimes conflicting, results across models. All models agree increasing average temperatures are likely; however, some predicted less than 0.5°C warming while others predicted 2.0°C warming when comparing the periods of 1980-2000 to 2020-2040. Rainfall predictions were even less consistent with different models predicting positive and negative rainfall trends in each of the 12 regions (Lobell et al., 2008). In many regions, rainfall and other weather patterns are largely affected by oceanic oscillations such as El Niño Southern Oscillation (ENSO), which are determined by atmospheric pressure and sea-surface temperatures (NOAA, 2008). For example, ENSO events are associated with increased rain in northern Peru (Khalil et al., 2007) and decreased rain in India and Malawi, and are inversely correlated with hurricanes in the Caribbean (Osgood et al., 2007; McPhaden, 2002). Scientists fear that documented increasing sea surface temperatures attributed to climate change may result in substantially different global rainfall patterns due to changes in oceanic oscillations (Merryfield, 2006). Thus, despite general agreement among scientists that global warming and increasing intensity of rainfall are likely to continue occurring, the amount of change is largely uncertain. Perhaps even more important for our discussion, predicting climate changes on a regional level to a practicable degree is not currently possible (Lobell et al., 2008).

Affects of Climate Change on the Price of Insurance

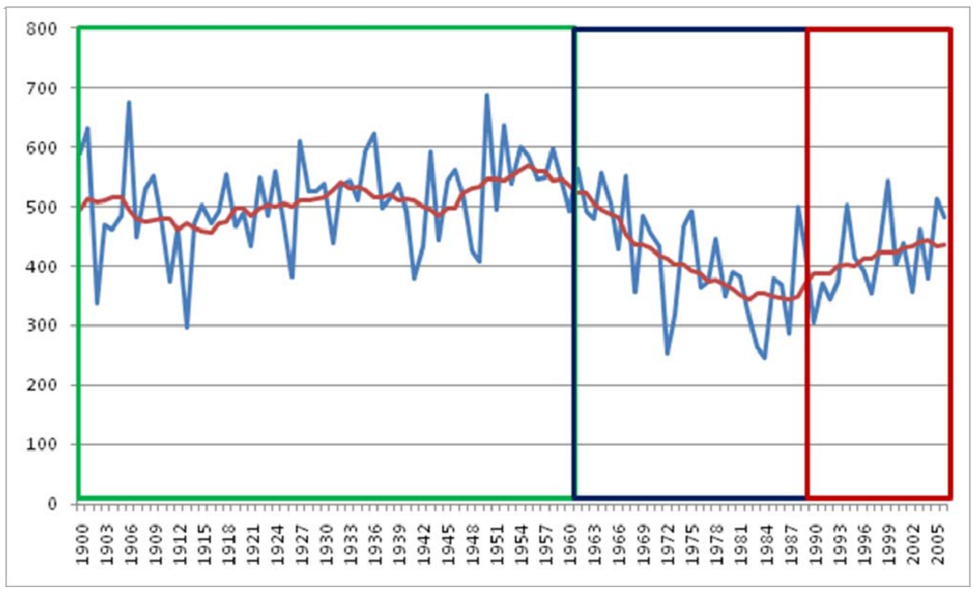
The great uncertainties associated with climate change at the regional level are problematic because development of weather index insurance depends on historic weather data and the appropriateness of weather index insurance largely depends on the extent to which climate change is affecting the insured weather risk in a region. Because weather index insurance incorporates the pure risk and ambiguity and catastrophe loads into the price of insurance, climate changes that increase the weather risk can greatly affect the price of insurance. This combination of increasing costs can quickly make insurance unaffordable to farmers and challenge the long-term viability of an insurance program.

Climate change resulting in increasing weather risk affects the price of insurance in two ways. First, ambiguity and catastrophe loads increase. Uncertainty associated with climate change leads insurers to plan for the worst of likely scenarios when establishing ambiguity and catastrophe loads. Second, increasing weather risk changes the pure risk, which may be best understood in terms of how it affects the probability density functions of specific weather variables. The first estimate of the cost of risk emerges using approximations of the underlying probability density functions. Changes in weather risk occur in two important ways: shifting the median of weather events—the central tendency, and increasing the variability of weather events—increasing the variance of the distribution. In some cases, these two changes can be occurring simultaneously.

Shifts in the Central Tendency. Shifts in the central tendency of the weather risk occur when the norm—the pattern of weather that occurs most often—changes. These changes can dramatically increase the cost of insurance. To illustrate, we consider 3 rainfall distributions from the Sahel and how the pure risk associated with a hypothetical rainfall insurance contract would change depending on the weather risk.

The Sahel, a region in Africa south of the Sahara, has a dynamic climate—experiencing multi-decadal trends in rainfall due to oceanic oscillations (Desanker and Magadza, 2001; Hulme et al., 2001). Figure 1 shows rainfall in the Sahel during the summer growing season from 1900 to 2006[12]. The blue line is the annual data; the red line is a 10-year moving average. To illustrate some core principles, we assume that an insurer enters into this environment at three different points in time and has only a limited amount of data when they develop an index insurance against shortages in rainfall. The first time period is from the vantage point of 1962. Looking back the insurer has data from 1900 to 1961. The second time period is from the vantage point of 1990 assuming that the insurer only has data from 1962 to 1989. Finally, the last time period is 2007 assuming that the insurer only has data from 1990 to 2006. The green, blue, and red boxes around the data in Figure 1 identify the time periods of data for the 3 probability density functions we will examine below.

Figure 1 Sahel Rainfall Distribution 1900 to 2006[13]



Insurers would adjust these data for trend—re-centering rainfall around the central tendency. Again, the adjustments would occur at three different vantage points (1962, 1990, and 2007) using only the data in the period described above. Under these conditions, the total data set after the independent trend adjustments is represented in Figure 2.

[12] These data are averaged across weather stations across the Sahel with the majority of stations concentrated in the western-most region.

[13] Source for Figures 1–6: GlobalAgRisk, 2008, based on data provided by International Research Institute for Climate and Society, Columbia University

Figure 2 Weather Data Adjusted for Trends Given the Vantage Point of 1962, 1990, and 2007

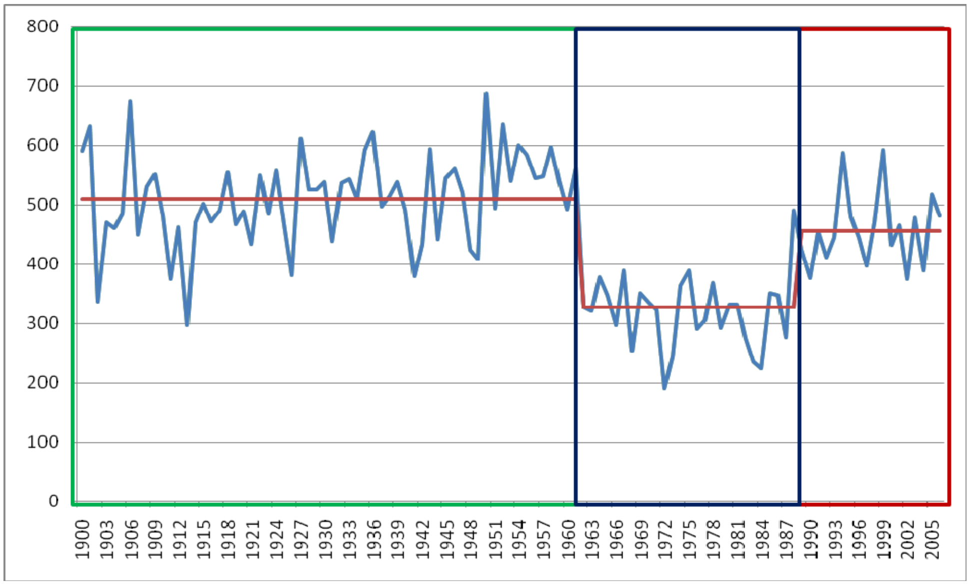


Figure 3 Rainfall Distribution for the Sahel Using Data from 1900 to 1961

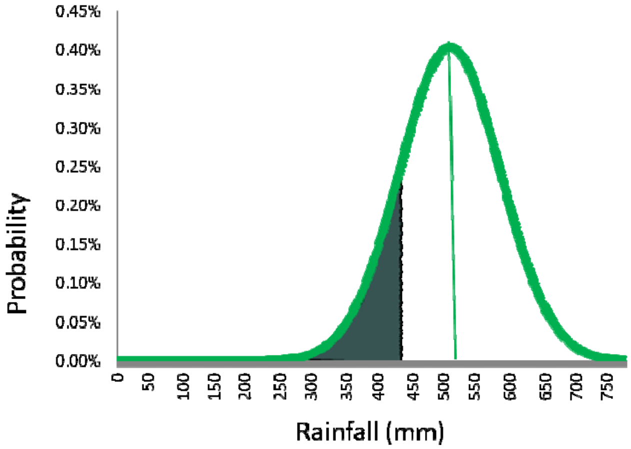


Figure 4 Rainfall Distribution for the Sahel Using Data from 1962 to 1989.

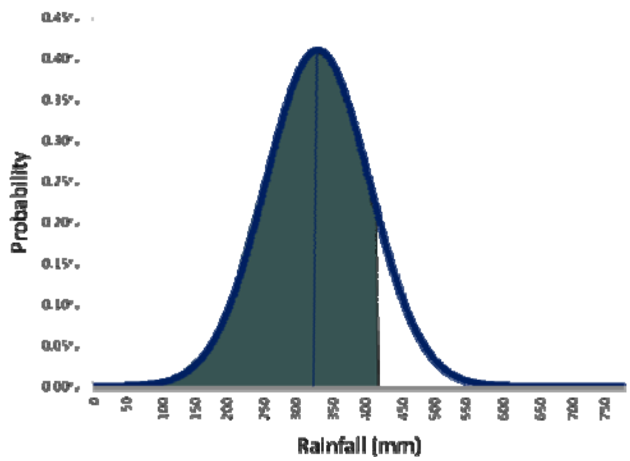
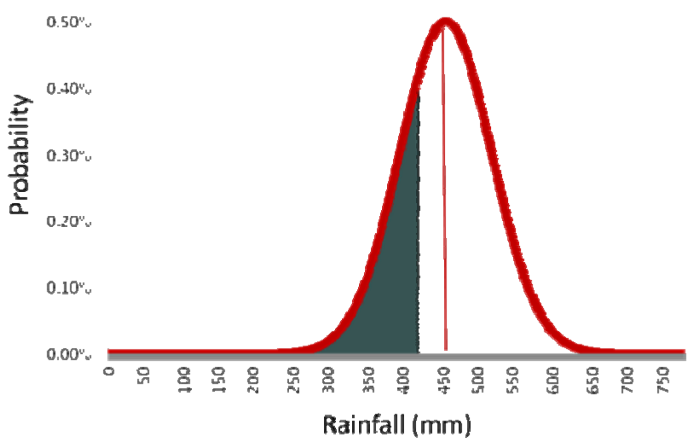


Figure 5 Rainfall Distribution for the Sahel Using Data from 1990 to 2006



Suppose that our hypothetical insurer decided to offer weather index insurance at these three different points in time (1962, 1990, and 2007). The contracts are designed for wheat farmers. Also, suppose wheat yields decrease significantly when rainfall is less than 425 mm during the growing season—thus insurers use this as the threshold for triggering indemnities. Indemnities increase uniformly for every mm of rainfall less than 425 mm. At 200 mm, total crop failure is assumed and maximum payout, 100 percent of the value insured, is reached. Given the details of this hypothetical contract, insurers would look at the probability density function for rainfall to determine the pure risk. Data from the three vantage points—1962, 1990, and 2007—would yield three different probability density functions—Figures 3, 4, and 5, respectively.

Figure 3 is a probability density function using data from 1900 to 1961.[14] In this period, the central tendency of rainfall is 510 mm. With a threshold of 425 mm, the pure risk of this hypothetical contract is 2 percent. The pure risk is the shaded area under the curve, which takes the frequency and severity of the weather risk into account. A pure risk of 2 percent indicates that insurers expect on average to pay indemnities equal to 2 percent of the total sum insured over the long term. This is a relatively low level of pure risk and would likely lead to an insurance contract that is affordable for farmers.

Figure 4 is a probability density function using data from 1962 to 1989. During this time period, rainfall decreased dramatically (see the blue box in Figure 1). The central tendency for this time period is 328 mm, which is below the threshold of 425 mm. The pure risk is very high— 44 percent. Again, the pure risk is the estimate of the actual risk transferred to the insurer, so over the long term the insurer would expect to pay $44 for every $100 insured, leading to a very expensive contract for farmers. These costs would increase further after considering the other costs factors for insurance (see the earlier sections). Additionally, the insurance product would be expected to pay indemnities in nearly every year because the central tendency is less than the threshold! Insurance is not designed for this scenario and would be an inefficient solution. Plus, farmers would be unable to pay for insurance products underwriting this level of risk. Adding subsidies to make such insurance affordable would be expensive and could distort production decisions in undesirable ways.

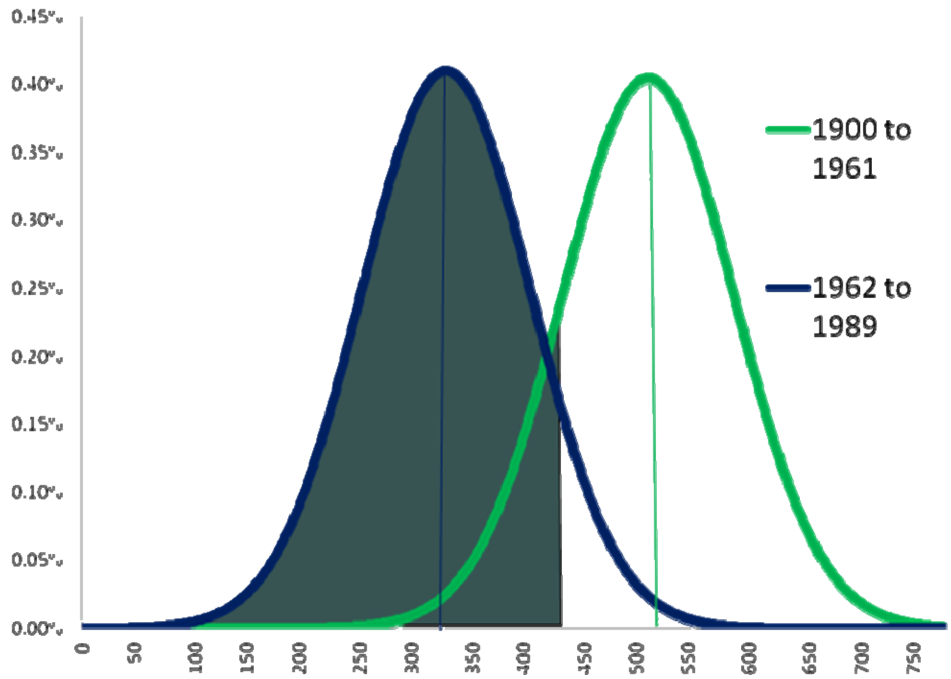
Figure 5 is a probability density function using data from 1990 to 2006. During this time period, rainfall increased (see the red box in Figure 1). The forecasted central tendency is 456, and the pure risk is 6 percent. Depending on the other costs associated with the price of the insurance (e.g., costs of the ambiguity load, administrative and delivery costs, etc.), the policy may be affordable to farmers.

In sum, we see that shifts in the central tendency can have dramatic effects on the pure risk and, thus, the price of insurance. As described in the previous section, scientists widely agree that climate change will affect the central tendency of many weather variables that are critical to agricultural production, but there is no consensus on the magnitude of those effects. Because changes in the central tendency so dramatically affect the pure risk, insurers (whether selling weather index insurance or MPCI) will respond to this lack of consensus by adding large ambiguity and catastrophe loads to premium rates. To illustrate why insurers take these precautions, consider the problem of using historical data to predict future trends in the presence of climate change. Figure 6 overlays the Sahel probability density functions using data from 1900–1961 and 1962–1989.

---

[14] For illustration purposes, we present probability density functions that are normally distributed; however, few weather variables actually follow symmetric distributions.

Figure 6 Comparing Rainfall Distributions and Payouts for Periods 1900–1961 and 1962–1989

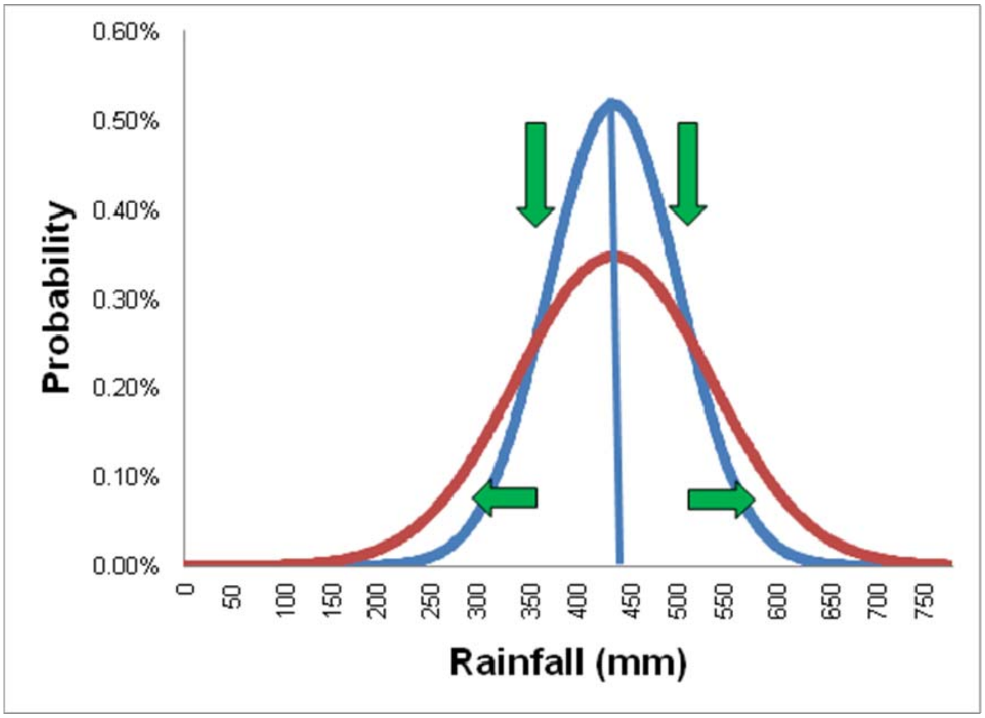


In 1962 an insurer would have priced rainfall insurance based on the green distribution but the blue distribution reflects rainfall over the subsequent three decades. Thus, the insurer would have experienced significant losses because of the changing climate conditions. The insurer would have continually adjusted prices to account for its loss experience; however, because these two time periods are so different, it is unlikely the insurer could adjust prices quickly enough to remain solvent. Concern about scenarios such as this is why insurers add large ambiguity loads when insuring against weather events.

While the Sahel data dramatically illustrate problems associated with changes in the central tendency, the Sahel is a somewhat unique example. Its dramatic multi-decadal rainfall cycles and relatively constant variance make it a useful case for this illustration; however, the Sahel experience is not consistent with future climate change scenarios. The dynamic climate of the Sahel seems to be the result of a complex interaction of natural and human factors—oceanic oscillations decrease rainfall which leads farmers to overextend natural resources increasing desertification (Desanker and Magadza, 2001; Hulme et al., 2001). Some of this damage is reversed as the oscillations (and farmer behaviors) change and rainfall increases in the Sahel. Unlike the oscillating rainfall patterns of the Sahel, climatologists believe that climate change will lead to more permanent changes that differ in terms of the degree of change and their effects on the central tendency and variance of weather patterns by region.

Increasing Variability. Insurance prices are very sensitive to shifts in the central tendency of the underlying loss distribution. Changes in the variability of the loss distribution (e.g., changes in the variance of the probability density function of the underlying weather variable) also affect insurance pricing, but less so than changes in the central tendency. Carter et al. (2006) report increasing rainfall variability is likely to occur in some regions as a result of climate change. In these regions, insurance contracts may be needed to cover excess and deficit rainfall—both tails of the distribution as illustrated in Figure 7. When the variance increases, events around the central tendency are relatively less likely to occur and events in the tails of the distribution are more likely to occur.

Figure 7 Increasing Weather Variability Increases the Variance of the PDF



Source: Authors

Important Lessons

As we have illustrated, climate change can create great difficulties for insurance programs. Even relatively minor evidence of climate changes can lead insurers to dramatically increase ambiguity and catastrophe loads, which is largely due to the imprecision with which future climate trends can be predicted at regional and sub-regional levels.

Beyond these loads, how climate change occurs and the magnitude of these changes are the biggest issues affecting the price of insurance and the long-run viability of weather index insurance markets in a region. The Sahel data illustrate that insurance costs are very sensitive to shifts in the central tendency—the core component to pricing the pure risk. Primarily, this is because the central tendency describes the set of conditions that are most likely to occur so misestimating the central tendency can result in large losses. Climate change makes the central tendency a moving target increasing the likelihood that insurers will misestimate it. In regards to increasing variance, indemnity payments are likely to increase, though not to the degree as would occur with changes in the central tendency, making insurance more workable in these scenarios. Of additional concern, shifts in the central tendency and increases in variance are likely to occur concurrently in many areas.

Thus for several reasons, climate change that increases the weather risk will increase the price of insurance, and can quickly make it unaffordable for farmers. However, this price signal provides the benefit of helping farmers see the cost of risk more clearly and pushes them to make difficult choices—farmers can continue in the same farming practices as production risks increase or they can adapt to the new climate conditions (Mileti, 1999).

Adapting to Climate Change

When climate change occurs, increasing weather risk results in increasing farm losses. The only way to reduce farm losses is to change production behavior. Farmers can adjust their crop portfolios to be less vulnerable to the increasing risks. Farmers could also invest in irrigation or inputs that reduce the likelihood of losses. In extreme cases, farmers may decide investing resources in other areas may be more profitable than farming. For instance, the farmer or a member of the family might pursue nonfarm labor in a nearby town, city, or even another country as remittances have proven to be an effective source of income for the poor in lower income countries. In sum, the solution for farmers facing climate change is to adapt—to change their investment portfolios in response to the new risk environment.

When farmers can do so, many will respond to price signals and adapt by changing crops or diverting labor to other sources of income because these tactics are more profitable for the farmer; however, this process can be difficult and expensive. Some farmers, especially the poorest farmers, may be unable to adapt without the assistance of governments and donors. Additionally, some lower income countries may not have the resources to adapt without the assistance of higher income countries and multilateral organizations.

Policy Interventions and Climate Change

Because adapting to climate change—whether by changing farming systems or changing occupations—can be very difficult and costly for farmers, opportunities abound for governments and donors to facilitate this process. Yet, given the uncertainties regarding the impact of climate change in different regions, policy makers have struggled with prioritizing interventions to improve farmer adaptation. Several types of interventions are noteworthy given the potential adaptations farmers must make.

Improved seed varieties may be very important for future food insecure regions. Development of seed varieties that are suitable for the emerging climate conditions can greatly benefit farmers who have sunk costs and specialized skills in a particular type of farming. Institutions funding these developments may take different approaches depending on their priorities—e.g., some institutions may focus on cases in which negative impacts are most likely to occur, such as maize and wheat production in southern Africa, while others may focus on preparing for the worst possible scenarios (Lobell et al., 2008).

Investments in infrastructure can also be quite important for farmer adaptation. Irrigation can greatly benefit farmers facing rainfall declines; however, decreasing rainfall will likely reduce available water supplies limiting opportunities for irrigation in many regions. Improvements in roads can increase farmers' access to distant markets for new agricultural commodities. Similarly, road improvements can increase access to labor markets, improving opportunities for transitions to new livelihoods.

Farmer training can also be important. Extension services that educate farmers in new farm management systems such as switching crops or improving water management can facilitate farmer adaptation. Also, because some rural families have specialized in agriculture for many generations, programs that provide farmers with new technical skills may be particularly appropriate when climate change is so severe that farmers must transition to new livelihoods.

Insurance Is not a Means of Adaptation

Unlike these examples, purchasing insurance is not truly a means of adaptation because it does not address the underlying problem—that climate change is causing traditional agricultural production to become riskier (Mileti, 1999). When farmers purchase agricultural insurance, they transfer production risk to the insurer, but because the risk is increasing due to climate change, insurers raise the price of insurance. Nevertheless, if carefully designed, weather index insurance can improve access to credit that is needed to implement new strategies of adaptation such as adopting more drought tolerant varieties (to some extent this was accomplished with the Malawi weather insurance pilot; Skees and Collier, 2007). Working on how to integrate weather index insurance into a broader adaptation strategy is desperately needed. Index insurance by itself will not be an effective adaptation strategy.

Some policy makers have suggested that when climate change increases the cost of index insurance beyond the means of farmers, the government should intervene and pay a portion of farmer premiums so that they can continue farming at a profit. While these propositions are well-intended, policy makers should maintain caution in pursuing this strategy. Premium subsidies can disrupt price signals that may encourage farmers to adapt to climate change. In fact in some cases, subsidizing insurance premiums can actually slow the adaptation process, working at cross purposes with other adaptation assistance programs.

Experience in the United States and other developed nations attest to the problems created by distortions tied to premium subsidies and free disaster assistance. U.S. policies regarding disaster relief and insurance subsidies have contributed to increasing losses and increasing government costs over time (Goodwin Vandeveer, and Deal, 2004; Skees, 2001). When the government pays a portion of total farmer premiums, it tends to benefit the riskiest farmers, those who have the highest insurance premiums, the most. This can actually encourage farmers to take more risks by planting on more marginal lands because if farmers lose crops, insurance will cover the losses and if farmers have a good year, they retain the profits. Additionally, free disaster assistance has led American farmers to plant on marginal lands that had otherwise been too unprofitable to farm. These experiences illustrate the maxim: if people are paid to take more risks, they will.

Insurance Facilitating Adaptation to Climate Change

If climate change causes increasing variability but not a significant change in the central tendency, more opportunities exist for using government-supported insurance products without greatly distorting adaptation incentives. In these contexts weather index insurance can be a valuable mechanism to protect farmers as they adapt to new climate conditions. We provide suggestions regarding how policy makers can reduce the likelihood that insurance products will result in externalities that hinder adaptation to climate change.

First, a risk layering approach in which the government captures the most extreme layer of risk may be feasible if climate change causes increased weather variability (without major changes in central tendency).[15] Increased variability increases the likelihood of catastrophic weather events. Yet studies have shown that: 1) individuals typically do not know the likelihood, or potential magnitude, of catastrophic weather events; 2) they are unable or unwilling to consider the potential impacts of low-probability catastrophic events; and 3) they

[15] The proposed risk layering approach is similar to that of the structure of the Index Based Livestock Insurance Program that is underway in Mongolia (See Mahul and Skees, 2007).

tend to forget about past extreme events (Buzby et al., 1994; Rossi, Wright, and Weber-Burdin, 1982; Kunreuther and Slovic, 1978; Kunreuther, 1976). To account for this cognitive failure, the government could subsidize the most extreme layer of risk—that layer for which individuals fail to plan (Skees and Barnett, 1999). Because individuals generally fail to take such low frequency, high severity events into consideration, subsidies that are limited to a catastrophic layer are less likely to affect adaptation decisions.

These subsidies also create opportunities for private insurers to sell products that complement the government subsidized catastrophic layer by insuring against more frequent but less extreme events. The government catastrophic coverage should reduce the cost of the complementary insurance product for three reasons. First, the pure risk is lower because the private insurance product does not have to cover the catastrophic layer of risk. Second, the need for catastrophic loading is greatly reduced. Third, the ambiguity load can also be reduced because the ambiguity is greatest for low-probability, high consequence, catastrophic events.

Regarding our second policy recommendation to the extent possible, insurance products should not reduce the farmer's choice set of adaptation strategies. Government interventions for a specific crop or even specific industry (agriculture) can entrench farmers in maladaptive behavior (Goodwin, Vandeveer, and Deal, 2004). For example, if governments choose to provide premium subsidies for a major local crop (e.g., cotton) it may prevent farmers from transitioning to different crops that are less sensitive to the new weather conditions. Also, if the government chooses to subsidize farm production, it may discourage farmers from diverting resources to other livelihoods that are less affected by the increasing weather risks. This is an advantage of weather index insurance over traditional MPCI. Weather affects many types of livelihoods (e.g., the agricultural value chain, tourism, and transportation) so the introduction of properly designed weather index insurance may be less likely to discourage farmers from diverting resources to other livelihoods. Government support for weather index insurance (e.g., by providing the catastrophic layer of protection at no charge) could provide benefits to some farmers by giving them the flexibility to adjust their farming systems to changing climate conditions and benefits to other farmers by facilitating their transition to other livelihoods.

Summary and Conclusion

The history of insuring agriculture is a story of trying to insure correlated risks at prices that farmers can afford. Insurers underwriting correlated risks (such as many weather risks) must account for the possibility of very large losses in some years and relatively small losses in others. Thus, they must make special arrangements—holding capital reserves and purchasing reinsurance—that smooth losses over time. Of course, the costs of these arrangements must be factored into the price of the insurance.

Many governments have subsidized MPCI premiums, rationalizing it as necessary to ensure farmers access to correlated risk coverage. MPCI provides comprehensive coverage, but its structure introduces farm-level information problems that can be expensive for insurers to address. Indeed, the history of MPCI has shown that it is very expensive to administer and that it tends to be a luxury reserved for higher income countries that have large farms, relatively small agricultural sectors, and large government budgets. Government policies pertaining to MPCI have increased access to insurance but have also encouraged farmers to take on more risks.

Weather index insurance underwrites weather risk that is highly correlated with agricultural production. This structure reduces the asymmetric information problems associated with MPCI and theoretically makes weather index insurance less costly to administer than MPCI. However, weather index insurance is subject to basis risk and does not provide coverage against multiple perils. Initial experience with weather index insurance in lower income countries has been generally positive but time will provide more lessons regarding its long-term role.

Climate change poses a significant threat to lower income countries that may be less able to adapt to increasing weather risks. Using weather index insurance to help at-risk farmers should only be done in limited contexts. A core component of insurance pricing is establishing the probability distribution of the weather event, which is anchored on the central tendency. When climate change results in shifts in the central tendency, insurers can experience extreme losses if they do not accurately estimate the magnitude of the shift. Climate change resulting in an increasing variance can also increase indemnities and thereby, rising insurance costs, but mistakes in estimating the changing variance are not nearly as devastating for an insurer as mistakes in estimating a changing central tendency.

Changes in the probability distribution affect the pure risk of the insurance contract, but because of ambiguity regarding future climate conditions insurers rely on large ambiguity and catastrophe loads when they have reason to believe the climate is changing in the region.

In general, it is important to note that insurance pricing provides an important signal to those who are at risk about the potential probability and magnitude of loss. In areas where climate change is increasing the risk of traditional agricultural production, insurance pricing can signal farmers that they may need to consider alternative agricultural enterprises or even non-agricultural livelihood opportunities.

Government and donor premium subsidies do not necessarily address the problem of protecting farmers from climate change. Especially when climate change affects the central tendency, subsidies have the potential to retard farmer adaptation to changing conditions. Policy makers must work within the ambiguity surrounding climate change in their region, and when there are reasons to believe that significant changes in the central tendency are occurring or are likely to occur, interventions that help farmers adapt farming practices or change livelihood strategies are likely betters uses of government and donor resources.

In the contexts in which weather index insurance seems to be feasible during climate change (e.g., very minor changes in the central tendency and/or increasing weather variability), carefully designed government subsidies may be able to increase farmer access to insurance without greatly affecting adaptation decisions. In particular, government provision of free insurance coverage for a catastrophic layer of risk would provide an implicit subsidy that is less likely to create perverse behavioral incentives. Also, farmer flexibility and adaptation opportunities are maintained if governments and donors support weather index insurance products that have applications beyond just insuring a specific agricultural crop. Such index insurance products may be applied to other agricultural endeavors or off-farm enterprises.

Climate change is likely to create a host of opportunities for governments and donors to provide valuable assistance to farmers in lower income countries. Making the most of these opportunities will require collaborative undertakings to prioritize a number of complementary efforts in a coherent manner. In some cases, insurance should not be included among those priorities. In others, carefully crafted insurance products can help protect farmers as they make difficult transitions.

References

Agroasemex. "The Mexican Experience in the Development and Operation of Parametric Insurances Applied to Agriculture." Working Paper, 2006a.

———. "The Mexican Experience in the Development and Operation of Parametric Insurance Oriented to Livestock." Working Paper, 2006b.

Alderman, H., and T. Haque. "Insurance against Covariate Shocks: The Role of Index-based Insurance in Social Protection in Low-Income Countries of Africa." Working Paper 95, Africa Region Human Development Department, The World Bank, Washington, DC, March, 2007.

Barnett, B. J. "The U.S. Federal Crop Insurance Program." *Canadian Journal of Agricultural Economics* 48(2000): 539–551.

Barnett, B. J., and O. Mahul. "Weather Index Insurance for Agriculture and Rural Areas in Lower-Income Countries." *American Journal of Agricultural Economics* 89(2007): 1241–1247.

Barnett, B. J., C. B. Barrett, and J. R. Skees. "Poverty Traps and Index-based Risk Transfer Products." *World Development,* Forthcoming.

Belete, N., O. Mahul, B. J. Barnett, R. Carpenter, X. Cheng, W. Dick, X. Li, J. R. Skees, C. Stutley, A. Tchourumoff. "China: Innovations in Agricultural Insurance, Promoting Access to Agricultural Insurance for Small Farmers." Report for Sustainable Development, East Asia and Pacific Region Finance and Private Sector Development, The World Bank, Washington, DC, June, 2007.

Besley, T. "Nonmarket Institutions for Credit and Risk Sharing in Low Income Countries." *Journal of Economic Perspectives* 9(1995): 115–127.

Bindoff, N. L., J. Willebrand, V. Artale, A. Cazenave, J. Gregory, S. Gulev, K. Hanawa, C. Le Quéré, S. Levitus, Y. Nojiri, C.K. Shum, L. D. Talley, and A. Unnikrishnan. "Observations: Oceanic Climate Change and Sea Level." *Climate Change 2007: The Physical Science Basis, Working Group* I *Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).* S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor, and H. L. Miller, eds. Cambridge, UK, and New York, NY: Cambridge University Press, 2007.

Binswanger, H. P., and M. R. Rosenzweig. "Behavioural and Material Determinants of Production Relations in Agriculture." *Journal of Development Studies* 22(1986):503-539.

Bryla, E., and J. Syroka. "Developing Index-based Insurance for Agriculture in Developing Countries." Sustainable Development Innovation Brief, Issue 2, Policy Integration and Analysis Branch of the Division for Sustainable Development, United Nations, March, 2007.

Burgaz, F. J. "Il sistema delle assicurazioni agricole combinate in spagna." *La gestione del rischio in agricoltura: strumenti e politiche.* Rome, Italy: Edizioni Tellus, 2004.

Buzby, J. C., P. L. Kenkel, J. R. Skees, J. W. Pease, and F. J. Benson. "A Comparison of Subjective and Historical Yield Distributions with Implications for Multiple Peril Crop Insurance." *Agricultural Finance Review* 54(1994): 15–23.

Cárdenas, V. S. "Developmental Challenges in Using Catastrophic Bonds for Disaster Risk Management: The Mexican Experience." Presentation to the Sixth DPRI-IIASA Forum on Integrated Disaster Risk Management, Istanbul, Turkey, August 13–17, 2006.

Carter, M. R., S. R. Boucher, and C. Trivelli. "Concept Note: Area-based Yield Insurance Pilot Project for Peruvian Coastal Agriculture." BASIS Research Program, December, 2007.

Carter, T. R., R. N. Jones, X. Lu, S. Bhadwal, C. Conde, L. O. Mearns, B. C. O'Neill, M. D. A. Rounsevell, and M. B. Zurek. "New Assessment Methods and the Characterisation of Future Conditions." *Climate Change 2007: Impacts, Adaptation, and Vulnerability, Working Group II Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC).* M. L. Parry, O. F. Canziani, J. P. Palutikof, P. J. van der Linden, and C. E. Hanson, eds. Cambridge, UK, and New York, NY: Cambridge University Press, 2007.

Chakravati, J. S. *Agricultural Insurance: A Practical Scheme Suited to Indian Conditions.* Bangalore, India: Government Press, 1920.

Collier, B., and J. R. Skees. "Morocco: Weather Index Insurance and Climate Change." Case Study in Market-based Risk Management for Development Course II: Weather Risk Management for Agriculture, Online Disaster Risk Management Learning Program prepared by GlobalAgRisk, Inc., in consultation with CRMG, Forthcoming, 2008.

Collier, B., A. G. Murphy, and J. R. Skees. "India: From Pilot Programs to a Developing Market for Weather Index Insurance Products for Smallholder Farmers." Case Study in Market-based Risk Management for Development Course II: Weather Risk Management for Agriculture, Online Disaster Risk Management Learning Program prepared by GlobalAgRisk, Inc., in consultation with CRMG, Forthcoming, 2008.

Dean, C. Against *the Tide*. New York, NY: Columbia University Press, 1999.

de Janvry, A., M. Fafchamps, and E. Sadoulet. "Peasant Household Behavior with Missing Markets: Some Paradoxes Explained." *The Economic Journal* 101(1991): 1400–1417.

Dercon, S. "Wealth, Risk, and Activity Choice: Cattle in Western Tanzania." *Journal of Development Economics* 55(1998): 1–42.

Desanker, P. V., and C. Magadza. "Africa." *Climate Change 2001: Impacts,* Adaptation *and Vulnerability, Working Group II Contribution to the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPPC).* J. J. McCarthy, O. F. Canziani, N. A. Leary, D. J. Doken, and K. S. White, eds. Cambridge: Cambridge University Press, 2001.

Giné, X., R. M. Townsend, and J. I. Vickery. "Patterns of Rainfall Insurance Participation in Rural India." Staff Report 302, Federal Reserve Bank of New York, September, 2007a.

———. "Statistical Analysis of Rainfall Insurance Payouts in Southern India." *American Journal of Agricultural Economics* 89(2007b): 1248–1254.

Glauber, J. W. "Crop Insurance Reconsidered." American Journal of Agricultural Economics 86(2004): 1179–1195.

Glauber, J. W., and K.J. Collins. "Crop Insurance, Disaster Assistance, and the Role of the Federal Government in Providing Catastrophic Risk Protection." *Agricultural Finance Review* 62(2002): 81–101.

Goodwin, B. K., M. Vandeveer, and J. Deal. "An Empirical Analysis of Acreage Distortions and Participation in the Federal Crop Insurance Program." *American Journal of Agricultural Economics* 86(2004): 1058–1077.

Gurenko, E., and O. Mahul. "Enabling Productive but Asset-Poor Farmers to Succeed: A Risk Financing Framework." Policy Research Working Paper 3211, The World Bank, Washington, DC, February, 2004.

Hazell, P. B. R. "The Appropriate Role of Agricultural Insurance in Lower Income Countries." *Journal of International Development* 4(1992): 567–581.

Hazell, P. B. R., and J. R. Skees. "Insuring Against Bad Weather: Recent Thinking." *India in a Globalising World: Some Aspects of Macroeconomy, Agriculture, and Poverty.* R. Radhakrishna, S. K. Rao, S. Mahendra Dev, and K. Subbarao, eds. New Delhi: Academic Foundation and Hyderabad: Centre for Economic and Social Studies (CESS), 2006.

Hess, U. "Innovative Financial Services for Rural India: Monsoon-Indexed Lending and Insurance for Smallholders." Agriculture and Rural Development (ARD) Department Working Paper 9, The World Bank, Washington, DC, 2003.

Hess, U., and J. Syroka. "Weather-based Insurance in Southern Africa: The Case of Malawi." Agriculture and Rural Development (ARD) Department Discussion Paper 13, The World Bank, Washington, DC, 2005.

Hess, U., W. Wiseman, and T. Robertson. "Ethiopia: Integrated Risk Financing to Protect Livelihoods and Foster Development." Discussion Paper, October, 2006. http://www.lead.virtualcenter.org/en/ele/econf_03_alive/download/s1_10_Ethiopia.pdf (Accessed April 2, 2008)

Hess, U., J. R. Skees, A. Stoppa, B. J. Barnett, and J. Nash. "Managing Agricultural Production Risk: Innovations in Developing Countries." Agriculture and Rural Development (ARD) Department Report 32727-GLB, The World Bank, Washington, DC, June, 2005.

Hulme, M., R. Doherty, T. Ngara, M. New, and D. Lister. "African Climate Change: 1900–2100." *Climate Research* 17(2001): 145–168.

Ibarra, H., and O. Mahul. "Self-Insurance Funds as Agriculture Insurance Providers: The Case of FONDOS in Mexico." Working Paper from the Contractual Savings and Insurance Practice, Financial Sector Operations and Policy Department, The World Bank, Washington, DC, November 2, 2004.

Ibarra, H., and J. Syroka. "Case Studies for Agricultural Weather Risk Management." *Risk Management in Agriculture for Natural Hazards*. Rome: ISMEA, 2006.

Isom, W. R. "Traditional Catstrophic Reinsurance and CAT Bonds." Presented at Expert Meetings of the Catastrophe Insurance and Weather Risk Management Markets for National Meteorological and Hydrological Services, WMO Headquarters, Geneva, Switzerland, December 5–7, 2007.

Khalil, A. F., H. H. Kwon, U. Lall, M. J. Miranda, and J. R. Skees. "El Ninõ–Southern Oscillation–based Index Insurance for Floods: Statistical Risk Analyses and Application to Peru." *Water Resource Research,* Vol. 43, No. 10, Manuscript #2006WR005281, October 17, 2007.

Kunreuther, H. "Limited Knowledge and Insurance Protection." *Public Policy* 29(1976): 227–261.

Kunreuther, H., and P. Slovic. "Economics, Psychology, and Protective Behavior." *American Economic Review* 68(1978): 64–69.

Leftley, R., and S. Mapfumo. Effective Micro-Insurance Programs to Reduce Vulnerability. Paper commissioned for the Global Microcredit Summit Campaign, Nova Scotia, Canada, November 12–16, 2006. http://www.opportunity.net/publications/pub.reduceVulnerability.asp

Lilleor, H. B., X. Giné, R. M. Townsend, and J. I. Vickery. "Weather Insurance in Semi-Arid India." Research Paper, Development Economics Research Group, The World Bank, Washington, DC, March 23, 2005.

Linnerooth-Bayer, J., A. Amendola, N. Okada, and P. Shi. "Disaster Risk Management: Pro-active Financing to Reduce Vulnerability." *Environmental Hazards* 7(2007): 1–6.

Lobell, D. B., B. B. Marshall, C. Tebaldi, M. D. Mastrandrea, W. P. Falcon, and R. L. Naylor. "Prioritizing Climate Change Adaptation Needs for Food Security in 2030." *Science* 319(2008): 607–610.

Mahul, O., and J. R. Skees. "Managing Agricultural Risk at the Country Level: The Case of Index-Based Livestock Insurance in Mongolia." Policy Research Working Paper WPS4325, The World Bank, Washington, DC, August 1, 2007.

———. "Piloting Index-Based Livestock Insurance in Mongolia." Access Finance Newsletter, Issue 10, The World Bank Group, Washington, DC, March, 2006.

Manuamorn, O. P. "Scaling up Microinsurance: The Case of Weather Insurance for Smallholders in India." Agriculture and Rural Development Discussion Paper 36, The World Bank, Washington, DC, 2007.

———. "Review of Weather Index Insurance Project Developments in Thailand." Presentation to Weather Index Insurance: Weather Risk Management for Agriculture in Thailand Seminar, organized by the World Bank Office Bangkok and the Commodity Risk Management Group (CRMG) of the World Bank, Bangkok, Thailand, October 13, 2006.

Mapfumo, S. "Microinsurance Coverage for Agricultural Losses: Malawi." Presentation at the Risk for Rural Communities Conference, Swiss Re Centre for Global Dialogue, Rueschlikon, Switzerland, October 8–10, 2007.

McPeak, J. G., and C. B. Barrett. "Differential Risk Exposure and Stochastic Poverty Traps among East African Pastoralists." *American Journal of Agricultural Economics* 83(2001): 674–679.

McPhaden, M. J. "El Niño and La Niña: Causes and Global Consequences." *Encyclopedia of Global Environmental Change, Volume 1,* The *Earth System: Physical and Chemical Dimensions of Global Environmental Change*. M. C. MacCracken, and J. S. Perry, eds. Hoboken: John Wiley and Sons, Ltd., 2002.

Merryfield, W. J. "Changes to ENSO Under CO_2 Doubling in a Multimodal Ensemble." *Journal of Climate* 19(2006): 4009–4027.

Mileti, D. S. *Disaster by Design: A Reassessment of Natural Hazards in the United States*. Washington, DC: Joseph Henry Press, 1999.

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

NOAA (National Oceanic and Atmospheric Administration). "Multivariate ENSO Index (MEI)." Earth System Research Laboratory: Physical Sciences Division Webpage. http://www.cdc.noaa.gov/people/klaus.wolter/MEI/ (Accessed April 2, 2008)

O'Hearne, B. "Case Study No. 3: Millenium Village Project." Presented at Expert Meetings of the Catastrophe Insurance and Weather Risk Management Markets for National Meteorological and Hydrological Services, WMO Headquarters, Geneva, Switzerland, December 5–7, 2007.

Osgood, D.E., M. McLaurin, M. Carriquiry, A. Mishra, F. Fiondella, J. Hansen, N. Peterson, and N. Ward. 2007. "Designing Weather Insurance Contracts for Farmers in Malawi, Tanzania, and Kenya." Final Report to the Commodity Risk Management Group (CRMG), World Bank, International Research Institute for Climate and Society (IRI), Columbia University, 2007.

Pikor, G., and A. Wile. "L'esperienza canadese nella gestione del rischio in agricoltura." *La gestione del rischio in agricoltura: strumenti e politiche.* Rome, Italy: Edizioni Tellus, 2004.

Rao, K. N. "India: Government Framework for Agricultural Insurance" Agriculture Insurance Company of India, Ltd. presentation to the Risk for Rural Communities Conference, Swiss Re Centre for Global Dialogue, Rueschlikon, Switzerland, October 8–10, 2007.

Rejda, G. E. *Principles of Risk Management and Insurance*. 7th ed. Boston: Addison Wesley Longman, 2001.

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

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

Rossi, P., J. Wright, and E. Weber-Burdin. *Natural Hazards and Public Choice: The State and Local Politics of Hazard Mitigation*. New York: Academic Press, 1982.

Shynkarenko, R. "Introduction of Weather Index Insurance in Ukraine — Obstacles and Opportunities." Presentation to the 101st EAAE Seminar on Management of Climate Risks in Agriculture, Berlin, Germany, July 5–6, 2007.

Skees, J. R. "Challenges for Use of Index-based Weather Insurance in Lower Income Countries." *Agricultural Finance Review*, in press, April, 2008.

———. "The Bad Harvest: More Crop Insurance Reform: A Good Idea Gone Awry." *Regulation: The CATO Review of Business and Government* 24(2001): 16–21.

———. "Agricultural Risk Management or Income Enhancement?" *Regulation: The CATO Review of Business and Government* 22(1999): 35–43.

Skees, J. R., and B. J. Barnett. "Challenges in Government-Facilitated Crop Insurance." *China in the Global Economy: Rural Finance and Credit Infrastructure in China.* Proceedings of the Organization for Economic Cooperation and Development (OECD) Workshop on Rural Finance and Credit Infrastructure in China, Paris, France, October 13–14, 2003, OECD Publishing, May 7, 2004.

Skees, J. R., and B. J. Barnett. "Conceptual and Practical Considerations for Sharing Catastrophic/Systemic Risks." *Review of Agricultural Economics* 21(1999): 424-41.

Skees, J. R., and B. Collier. "Weather Risks, Index Insurance, and Developing Financial Services for the Rural Poor." *Microfinance Insights*, December, 2007, pp. 31–33.

Skees, J. R., and A. Enkh-Amgalan. "Examining the Feasibility of Livestock Insurance in Mongolia." Policy Research Working Paper 2886, Rural Development and Natural Resources Sector Unit East Asia and Pacific Region, The World Bank, Washington, DC, September 17, 2002.

Skees, J. R., and A. J. Leiva. "Analysis of Risk Instruments in an Irrigation Sub-Sector in Mexico." Report prepared for the Inter-American Development Bank Technical Cooperation Program and IDB-Netherlands Water Partnership Program, June 30, 2005.

Skees, J. R., and M. R. Reed. "Rate-Making for Farm-Level Crop Insurance: Implications for Adverse Selection." *American Journal of Agricultural Economics* 79(1997): 430–438.

Skees, J. R., J. R. Black, and B. J. Barnett. "Designing and Rating an Area-Yield Crop Insurance Contract." *American Journal of Agricultural Economics* 79(1997): 430–438.

Skees, J. R., J. Hartell, and A. G. Murphy. "Using Index-based Risk Transfer Products to Facilitate Micro Lending in Peru and Vietnam." *American Journal of Agricultural Economics* 89(2007):1255–1261.

Skees, J. R., U. Hess, and H. Ibarra. "Crop Disaster Assistance in Ukraine: Issues, Alternatives, and Consequences." World Bank Rural Finance Project P076553, Washington, DC, December, 2002.

Skees, J. R., S. Gober, P. Varangis, R. Lester, and V. Kalavokonda. "Developing Rainfall-based Index Insurance in Morocco." Policy Research Working Paper 2577, The World Bank, Washington, DC, April, 2001.

Skees, J. R., A. Goes, C. Sullivan, R. Carpenter, M. J. Miranda, and B. J. Barnett. "Index Insurance for Weather Risk in Low Income Countries." USAID Microenterprise Development (MD) Office, USAID/DAI Prime Contract LAG-I-00-98-0026-00 BASIS Task Order 8, Rural Finance Market Development, 2006.

Stoppa, A., and U. Hess. "Design and Use of Weather Derivatives in Agricultural Policies: the Case of Rainfall Index Insurance in Morocco." Paper presented at the international conference: "Agricultural Policy Reform and the WTO: Where Are We Heading?" Capri, Italy, June 23–26, 2003.

Swiss Re. "Swiss Re Launches Climate Adaptation Development Program Providing Financial Protection Against Weather Risk in Emerging Countries." Press release, September 27, 2007.

Syroka, J. "Weather Insurance for Small and Medium Farmers: Building a Weather Risk Market in Central America." WRMA Annual Meeting, Miami, Florida, May 9–11, 2007.

Syroka, J., and R. Wilcox. "Rethinking International Disaster and Finance." *Journal of International Affairs* 59(2006): 197–214.

USAID (United States Agency for International Development). "Hedging Weather Risk for Microfinance Institutions in Peru." Report prepared by GlobalAgRisk, Inc., under

USAID/DAI Prime Contract LAG-I-00-98-0026-00 BASIS Task Order 8, Rural Finance Market Development, November, 2006.

Wenner, M. "New Developments in Agricultural Insurance: A Latin American and Caribbean Perspective." Presentation to the Third Annual Microinsurance International Conference, Mumbai, India, November 13–15, 2007.

WBI/CRMG (World Bank Institute, and Commodity Risk Management Group). "Market-based Risk Management for Development Course II: Weather Risk Management for Agriculture." Online Disaster Risk Management Learning Program prepared by GlobalAgRisk, Inc., in consultation with CRMG, Forthcoming, 2008.

Wu, J. "Crop Insurance, Acreage Decision, and Nonpoint-Source Pollution." *American Journal of Agricultural Economics* 81(1999): 305–320.