Index Based Agricultural Insurance in Developing Countries:

Feasibility, Scalability and Sustainability

By

Vincent H. Smith and Myles Watts[1]

1.   Introduction

Agricultural insurance has been offered to farmers in many different countries in many different forms since at least the 1920s. The current U.S. agricultural insurance program, for example, is a mix of 22 different types of program (including area yield and revenue programs and rainfall and vegetation index based products as well as multiple peril revenue and yield products for individual farms) covering over 130 different crops. The US program is often cited as a model for other countries because of high participation by farmers.   In 2008, the program achieved a record participation rate of just over 80 percent of the planted area eligible for insurance, about ten percent higher than in 2007 (Goodwin and Smith, 2009), but did so for two reasons. First, and most importantly, farmers did not have to pay any of the administration costs of the program (the loading factor is zero) and also had to pay only 40 percent of what were intended to be actuarially fair premium rates. Second, in 2008, to be eligible for U.S. crop disaster program payments, producers had to purchase agricultural insurance for all economically significant crops. As a result, agricultural insurance subsidy payments to U.S. farmers and crop insurance companies increased to almost $6 billion. Clearly, most developing country governments cannot afford to provide this type of program to their countries' farm households.

Multiple peril crop insurance, insurance that protects farmers against yield or revenue losses from multiple sources of risk on their own farms, has never been successfully offered by the private sector on a purely commercial basis (Gardner and Kramer, 1986; Hazell et al, 1986; Goodwin and Smith, 1995; Goodwin and Smith, 2009). Single peril insurance is a somewhat different story. Private insurers have been able to offer farmers protection against well-defined single perils like fire or hail that have potentially catastrophic consequences for their crop production.   The up-take of such products has varied in terms of potential market size and in some cases has been substantial[2] because, at least in developed countries, premium rates for single peril insurance products have been relatively low compared to liability (the maximum indemnity a farmer could receive) and to the farm household's net income.[3]

Perhaps (in part) because privately offered single peril contracts have been commercially feasible, index-based agricultural insurance has come to be viewed as a viable risk management tool for low income farmers in developing countries.   In addition, weather index products and related derivatives have been used by other sectors (for example, electric power utilities) to hedge against weather related risks.[4] A third, more important reason is that index insurance is perceived to be

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[2] Protection against livestock losses from events like lightening and auto collisions is often bundled within general property insurance products for farms in countries like the United States and Canada.

[3] Premium rates for single peril agricultural insurance have been relatively low because the incidence of insured events like range fires is rare and loss adjustment costs are relatively low (in large part because moral hazard behaviors are relatively easy to identify).

[4] See, for example, the discussion of temperature related products by Turvey (2001)

substantially less costly to operate and manage than multiple peril insurance.[5] However, there is one important distinction between index-based insurance and single peril insurance. Like multiple peril insurance, single peril insurance provides indemnities to a farmer when the farm experiences a crop loss because of the occurrence of the peril and those indemnities are directly linked to the size of the loss. Index insurance does not always provide farmers with indemnities when they experience crop or revenue losses on their farms and the indemnity payments often do not accurately reflect the size of the losses the farmers have experienced. Miranda (1991) described this problem with index insurance, which is now well understood by both insurers and academics, as "basis risk." As a direct consequence of basis risk, however much farmers may be willing to pay per dollar of liability for farm-based multiple peril or single peril insurance, they are almost surely willing to pay less for index based insurance.

Most developing country governments are not able to provide subsidies to farm households on a persistent basis. In those settings, crop insurance programs are likely to have to be self sufficient: that is, premium rates will have to cover both the indemnity, administrative and other overhead costs associated with the insurance program. A critical issue, therefore, is whether the risk reduction farmers obtain from index insurance is sufficiently valuable for them to be willing to pay for the overhead and administrative costs built into those premium rates.

A second important issue involves who will be insured under index insurance contracts and for what. The most obvious response is "farmers" but a literature has developed on the potential use of index insurance by financial institutions and agricultural input suppliers who extend credit to low income farmers in developing countries. Largely anecdotal evidence indicates that financial institutions, including micro-finance lenders, have abandoned rural areas after widespread crop losses have result in extensive defaults on farm loans. Similarly, fertilizer and other agricultural input supply companies like Syngenta have been reluctant to market their products to low income farm households by extending credit between planting and harvest because of concerns about loan repayments after harvest. One potential use of agricultural index insurance, therefore, is by financial and other institutions who lend to poor farmers to insure a part of their loan portfolios in different regions against widespread crop losses in those regions. The implication is that such an insurance program will allow those lenders to continue to supply credit in high production risk areas by reducing lender risks, enabling farms to adopt production technologies that on average generate higher crop yields and incomes but may involve more income risk. Almost certainly, however, private companies will include the costs they incur for insuring the loans they make to farmers in the prices they charge farmers for their products. These effects, to some extent, will offset the impacts of increased credit availability on farmers' incentives for adopting the technologies with which the companies' inputs are associated.

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[5] See, for example, Vedenov and Barnett (2004), who claim that such products solve both the moral hazard and adverse selection problems linked to individual farm-based, multiple peril products. Bourgeon and Chambers (2003), however, argue that area yield (and by association weather index products) are subject to adverse selection problems when they are offered in multiple areas which use different rating and indemnification schedules.

A third set of issues involves the structure of index based insurance programs. Weather index insurance contracts have been proposed and implemented and can take several different forms. Insurance programs based on satellite images of plant growth have also been proposed and implemented in developed countries. Area yield or production index programs for crops and, in Mongolia, for livestock have also been proposed and implemented either on a permanent basis (as in the United States and elsewhere) or on a pilot basis (as in Morocco, Malawi and Mongolia).

Scalability and sustainability are also important concerns for index insurance programs. Scalability involves three major elements: (1) access or coverage — the numbers of farmers who are eventually eligible to be insured by the program, (2) participation — the proportion of those farmers who choose to use the program, and (3) the cost of operating and administering the program (which affects participation because of the impacts on premium rates). Sustainability has at least two important elements: (1) the willingness of farmers to participate over the long term (from one year to the next) and (2) the ability of a country's public administration (regulatory agencies, etc.) and private insurance sector to deliver and manage the program after it has initially been established (often by third parties such as developed country and international aid agencies).

Given the above concerns, this report is structured as follows. We begin with a brief discussion of risk and, in general terms, the willingness of farm households to incur costs to avoid adverse income and food availability outcomes. In the following section, we describe the landscape for index insurance: what products have been implemented or proposed, how they have been structured, and the challenges they pose for private insurers and public agencies in terms of their practical implementation. We then examine the existing evidence on farmers' willingness to pay for agricultural insurance. Two areas of analysis are relevant in this context. Only a few studies have directly examined how much farmers are willing to pay for agricultural insurance. Two of those studies examine insurance contracts in which indemnities are directly linked to each farm's yield or revenue losses. Two other studies examine willingness to pay for rainfall index products in developing counties. A second and larger set of studies examines the demand for crop insurance and provides indirect insights about when farmers are more or less likely to purchase agricultural insurance. Most of these studies have also examined the demand for multiple peril insurance rather than index insurance. Next, we explore the issue of basis risk for index insurance and the extent to which it is likely to reduce a farmer's willingness to pay for index based coverage as opposed to multiple peril coverage. Scalability — which is closely linked to farmers' willingness to pay for insurance and the cost of providing that insurance — is then investigated. Sustainability and administrative costs of providing weather and other index insurance products are also discussed, together with potential synergies and cost savings associated with linking index insurance to other financial services, agricultural input supplies, or other elements of the agricultural production and marketing chain.

2.   Risk and Risk Mitigation in Agriculture

Many farmers, like most people, are concerned about events that have substantial adverse effects on their lives. In a developing country context, for low income farm households these events include crop and livestock losses that may lead to malnutrition and even starvation. Individuals who are wealthy (and possess valuable assets ranging from land to precious metals to financial assets like stocks, bonds and bank deposits) are more likely to self insure because they can more comfortably bear the risks of poor crop yields and low levels of livestock production. Individuals who are poor or have only moderate incomes are often willing to incur costs over and above the indemnities they expect to receive to reduce the likelihood that such adverse outcomes will occur.   In some cases, low and moderate income households are willing to incur costs that are large relative to their average incomes and/or assets to prevent or mitigate the consequences of catastrophic events.

Several factors affect the amount a household is willing to invest to partially or completely mitigate the effects of events that result in losses.   One is the *size of the potential loss relative to the household's income or wealth*.   For example, a middle income family in a developed economy like Australia or Japan is unlikely to purchase insurance against the theft of their children's bicycles largely because the bikes constitute a minimal proportion of their wealth (though they are likely to insist their children have and use bike locks, which are inexpensive relative to the value of the bikes). However, those households are very likely to purchase insurance against events like fire and water leaks that severely damage their houses because their houses constitutes a relatively large proportion of their wealth (typically over a third of all their assets) and loss of the house would have substantial adverse effects on their financial security.   In a developing country context, low income farm households may be willing to invest a substantial portion of their average income to protect themselves against even relatively modest crop losses because those losses are large relative to their wealth and may have catastrophic impacts on their financial and food security.

A second major factor is *the frequency with which losses occur*.   Yield volatility is the major issue for crop producers. Frequency of events that cause mortality and morbidity in animals, including forage loss, is the major concern for livestock operations.   When losses are infrequent (for example, they occur only once every 20 or 30 years), even though they may be large and have catastrophic consequences when they occur, farmers are generally reluctant to take costly actions to mitigate those potential losses.   More frequent loss experiences tend to generate loss mitigation efforts by farmers, even if those losses are relatively small (although not too small).

A third factor is *the expected severity of the actual loss*. Individuals are more likely to seek to mitigate risks of loss when the losses that are likely to occur are large rather than small. For example, farmers who raise irrigated crops are much less likely to suffer substantial yield losses that have severe consequences for their financial and food security than farmers who raise rain fed crops. Therefore, they are much less likely to seek loss protection by using risk-management products.

A fourth factor is the ***cost of risk mitigation***. In deciding about whether or not to use risk mitigation activities such as insurance, households weigh ***the costs of those risk mitigation activities against their expected benefits***. For example, numerous studies of the demand for crop insurance have reported that, other factors remaining unchanged, increases in premium rates reduce participation in crop insurance programs; fewer farms purchase insurance and those that do tend to purchase lower levels of coverage or protection (see, for example, Goodwin, 1992; Smith et al, 1994; Smith and Goodwin, 1996; Goodwin and Smith, 2003; and Knight and Coble, 1997). Thus the costs of risk mitigation are an important factor in a household's decision about whether or not to mitigate risk. For poor and very poor (subsistence) farm households, risk mitigation costs may be extremely important deterrents to the use of risk mitigation strategies. For example, a crop insurance product may provide a low income households with additional resources when yields are poor or even only somewhat below average. However, if the costs (premium rates) of the insurance are relatively large, then the resulting reductions in net farm incomes in average or even good years may be enough to create serious financial and food security problems for the household in those years.

Fifth, ***the extent to which a risk management strategy provides protection against losses when they occur*** is important. Other things being equal, farmers appear to strongly prefer agricultural insurance contracts that base indemnities on the losses they experience on their own farms. In other words, farmers prefer to buy contracts that provide indemnities when the yields and revenues from their own farms are low. One important reason is that farmers need the liquidity provided by insurance indemnities when they incur losses because access to financial capital marketed is typically more costly and more limited at those times. Index insurance products in which indemnities are imperfectly linked to a farm's actual loss experience are less attractive even when they provide farmers with the same average amount of subsidies because they cannot be relied on to always provide indemnities when a farmer suffers losses.

Sixth, whether or not, and how much, a farm household is willing to pay to adopt a specific risk management strategy depends on ***the availability and relative costs and benefits of other risk management strategies***. Farms can and do diversify in several ways, utilizing a portfolio of risk management strategies. A farm may diversify among on-farm enterprises (producing several crops and/or managing different livestock enterprises), spatially diversify farm operations (for example, raising a crop in several different locations), diversify household labor between on-farm and off-farm enterprises, manage debt,[6] and use inputs or make capital investments that reduce production risks (for example, building irrigation ditches). If those alternative risk management strategies are relatively inexpensive and effective, then a farm may not be willing to pay very much to obtain agricultural insurance.[7]

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[6] The current national average debt to asset ratio for farms in the United States is about 10 percent.
[7] Chambers and Quiggin (2002) provide one of the few analyses that explicitly consider the array of risk management options available to farmers who are considering using area yield insurance. While they are careful to qualify their findings, Chambers and Quiggin suggest that area yield insurance is unlikely to be preferred as a risk management tool in a developed country setting where well-organized contingent claims markets exist.

3.   The Agricultural Insurance Index Product Landscape

Self insurance, single peril insurance, multiple peril insurance and index insurance constitute the agricultural insurance landscape. Farmers, of course, can always choose to self insure and, in many developing countries, they have no other option.   Farm level insurance is available in several developed countries, but not in most developing countries. Single peril insurance against risks like hail and fire has been successfully offered by the private sector in many countries.   Multiple peril insurance at the farm level has only been offered on a continuous basis in settings where participation is voluntary if the government has been willing to provide substantial subsidies. Index insurance of various types has been widely proposed and has been implemented in several developing countries, for the most part on a pilot basis. Heavily subsidized index insurance programs have been offered in some developed countries but, where those products have competed with similarly subsidized farm level insurance products, farmers have usually left them on the shelf.

A general taxonomy of multiple peril and indexed based agricultural insurance programs is presented in table 1.   Multiple peril agricultural yield and revenue insurance programs have been offered at the farm (and sub-farm) level in the United States, Canada and elsewhere for individual crops as well as on a whole farm basis (multiple crop and livestock enterprises).   Those programs have offered insurance against yield loss, revenue loss, and reductions in crop quality. Index programs include products that have either been developed or proposed which are based on average area yields or revenues, weather indexes (precipitation and/or temperature), satellite measures of vegetation, and prices (typically national prices for commodities, inputs such as energy and feed, or a combination of both). Vegetation insurance for pasture and rangeland forage has also been offered at the farm level.

Proposals for index-based agricultural insurance can be traced back at least 60 years to Halcrow's argument in his University of Chicago PhD thesis (supervised by Professor D. Gale Johnson and reviewed by Milton Friedman) that the U.S. Federal Crop Insurance Corporation should offer an area yield insurance product.   Halcrow's major concern was that individual yield insurance resulted in an adversely selected pool of insured farmers (Halcrow, 1949, p 426).   In his study, Halcrow compared multiple peril crop insurance with both an area yield based insurance product and a "weather-crop insurance product." Halcrow proposed a weather index product based on "one or two measurable phenomena" which, he suggested, would most likely be rainfall and temperature in the locality of the farm purchasing insurance.   He concluded that, from a practical perspective, area yield insurance was likely to provide more reduction in revenue variability for producers of crops but that a weather product would probably be more appropriate for livestock producers who wanted to insure against loss of forage on grazingland (pasture or rangeland).   Halcrow recognized that indexes could be linked to larger or smaller geographic areas and that what we now call basis risk would be less of a problem for indexes based on smaller areas (like U.S. and Canadian townships) than larger areas (like U.S. and Canadian counties or U.S. states and Canadian Provinces).

Table 1: A Taxonomy of Multiple Peril and Index-Based Agricultural Insurance Products

	Multiple Peril Crop Insurance: Individual Farm Plans	Index Insurance: Area Plans
Yield and Revenue Insurance	Offered for single crop, multiple crops, crop quality, and whole farm	Offered for area yield and revenue
Weather Insurance	Not offered on a farm by farm basis	Offered using single and multiple Indicators (Weather and temperature)
Vegetation Insurance	Offered (at least in the United States for forage)	Offered (at least in the United States using satellite based vegetation indexes)
Commodity Price Insurance	Not offered on the basis of individual farm prices	Offered using national and futures price information (for example; LRP and AGM products in the US)

Index insurance proposals and products have not only been linked to direct or indirect (satellite-based) measures of area yields or indicators of local weather conditions. They have also included insurance products based on livestock prices and feed prices in commodity exchange spot and futures markets and used to construct agricultural commodity value indexes (LRP insurance products in the United States), indexes of gross margin values (AGM products in the United States), and indexes of input prices (for example, energy and fertilizer price indexes). However, much more attention has been given to weather and yield index insurance than other forms of index insurance. Several aspects of these programs are important, especially in the context of basis risk, and in some respects are similar for both weather and yield insurance. They include the geographic areas to which the programs apply, the structure of the contracts, the time periods to which the insurance applies, the premium rates farmers have to pay, and the types of subsidy program governments have operated.

(i). Geographic areas.

Area yield and/or revenue index products are typically developed for a single crop (wheat, maize, grain sorghum, etc). Weather index products may be developed for whole farm operations, as implied by recent proposals for Peru (Skees et al, 2007), or targeted to a single crop or livestock operations via forage related insurance (as in the U.S. Rainfall Index pilot program and the Kenyan livestock pilot program). Regardless of the index program, there is broad agreement that basis risk will be lower for programs based on smaller rather than larger geographic areas. There is also widespread evidence that, for a given area, rainfall indexes (and weather based indexes in general) have a greater basis risk than yield based indexes. For example, most studies have identified correlations between vegetation growth and precipitation of less than 0.7, and similar or smaller correlations have been identified between normalized difference vegetation indexes (NDVIs) obtained from satellite data[8] and "on the ground" plant growth.

Weather indexes have been proposed for crop insurance largely because of concerns about the data available for the implementation of area yield indexes. The availability of data on area yields has always been recognized as important (see, for example, Halcrow, 1949) and a factor that limits the utility of area yield products because basis risk almost surely monotonically increases as the geographic area expands. In Canada and the United States, yield data for major crops are available at

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[8] Normalized difference vegetation indexes are measures of greenness. In the United States, the data are provided by the U.S. Geological Survey Earth Resources Observation and Science data center. A serious concern with respect to NDVIs is that the major satellite used to provide the information on which they are based is expected to fail in the middle of the next decade (around 2015) and currently there appears to be no plan to replace it. A second concern is that the normalization procedures used to adjust the underlying data for differences in elevation and latitude seem to be relatively coarse and imprecise. The consequence is that NDVIs are generally relatively poorly correlated with actual plant growth even though the data are available for relatively small 8 by 8 kilometer grids. Informal suggestions to combine NDVI data (which is potentially available at a resolution of one square kilometer) and weather index information have been put forward with the objective of improving the correlation between a combined index and area crop yields as compared to the correlation between either an NDVI or a weather index and those yields. Currently, little publicly available research has been carried out in this area.

the county level but not for smaller geographic areas like townships. Therefore, area yield and revenue products have been developed at the county level in the United States. Basis risk is substantial at this level of aggregation and, if many farmers are to obtain a substantial degree of income smoothing, they have to be allowed to "over-insure" their crops by a considerable amount (Miranda, 1991; Smith et al, 1994). The corollary is that they have to pay relatively high premium rates to obtain that income smoothing and, from a practical perspective, basis risk cannot be completely removed.

In many developing countries, and especially the poorest countries, reliable current and historical data on average area yields are simply not available at the equivalent of the county level in developed countries like the United States, Canada, and Japan. Often, such data are not available on consistent basis at a regional level (for example, at a level analogous to states in the United States or provinces in Canada). Moreover, establishing and maintaining such databases solely for insurance purposes is expensive. In India, attempts have been made to construct proxy measures of average yields at the village level using test or representative plots for certain crops to represent those average yields. However, those proxy measures are subject to a variety of moral hazard problems which imply that actuarially sound programs cannot be based on such indexes. Key issues include manipulation of the plots in terms of their performance by villagers and local pressures on the managers of the plots to report yields that are beneficial for the insured farmers. Private reinsurers are unlikely to provide reinsurance for this type of product on a permanent basis and, as a result, the product is unlikely to be commercially viable.

Weather index data appears to be available for much smaller geographic areas. In the United States, for example, the National Oceanographic and Atmospheric Administration (NOAA) provides daily precipitation information for grids that are approximately 20 kilometers square and has done so since 1948 using data from approximately 12,000 weather stations, of which about 6,000 report information on a regular basis. However, even in the United States, no weather stations are located in most of the grids for which data are reported and variants of triangulation methods are used to estimate rainfall within in a grid from three or more weather stations that are closest to the grid of interest. Further (as discussed in section 5 below), the evidence suggests that even when precipitation is measured directly at locations where yield data are available the correlation coefficient between precipitation and plant yield is no more than 0.7.

In the context of Peru, two specific index product proposals have been considered. Carter (2009) has proposed using an area yield index product for cotton producers linked to average yields in a specific valley in which planted area and yields on irrigated land are partially though weakly linked to annual rainfall. Skees et al have (2008) have proposed a weather index product for farmers in Northern Peru based (apparently) on sea temperature conditions that indicate the advent of *El Nino* weather patterns that on occasion result in severe flooding. Carter and Skees et al have termed their proposed indexed insurance products "livelihood insurance" because index products can be used to provide protection against both livestock and crop losses by landless households as well as farmers

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who own land. Further, they could also be purchased by small and large agricultural businesses and private agricultural finance providers. It should be noted that the idea that farmers who do not own the land they farm can purchase insurance is not new.   Multiple peril and index insurance has been available to many farmers in developed and developing countries who lease some or all of their land on a cash lease or crop share basis.   Farm laborers, however, have not been able to obtain insurance against yield or livestock losses on the part of the farmers for whom they work. In many developing countries, and especially the poorest countries, these individuals and their families are the people who are most vulnerable from a financial and nutritional perspective when major shortfalls in agricultural production occur. It is not at all clear that their livelihoods could be protected by either area yield or weather index products (although the Peru *El Nino* product proposed by Skees would conceptually be available to all households in the area covered by the insurance).

(ii).   Contract Structures

An indexed based agricultural insurance contract has several key elements. Those elements include the event to be insured (in this case, precipitation and/or other weather indicators like temperature or area yield), the premium rate for the contract, the liability to which that rate applies (the maximum indemnity to be paid if a complete loss occurs), the premium payment (almost always equal to the premium rate multiplied by the liability), and a loss payment schedule. The loss payment schedule defines the size of the indemnity for any given event outcome.

In both weather index and area yield contracts, the expected area yield for the growing season is identified and valued at an expected price by the insurer.   In some cases (for example, in the United States), the farmer is allowed select the price at which a crop or forage loss is to be valued by choosing a percentage of the expected price, which can range from as little as 30 percent to 150 percent.[9] When a weather index is being used, the producer insures against a shortfall in the index which is then linked to the estimated per acre (or hectare) expected value of the crop in the area covered by the index for the amount of land planted to the insured crop by the farmer.   Under an area yield (or revenue) program, each producer is then allowed to insure a percentage of the expected area yield (or revenue), up to a predetermined maximum percentage, for the amount of land planted to the insured crop.

The producer receives an indemnity if the weather index or area yield index falls below the percentage of the weather index or expected area yield against which the producer selected to insure. For example, suppose the expected area yield for cotton in a Peruvian valley is 400 kilograms per hectare. A farmer who chooses to insure against 90 percent of that yield under an area yield program would receive an indemnity if the actual area yield were to fall below 360 kilograms (0.9*400 kg), the area yield which *triggers* an indemnity payment for her, often called the trigger yield.

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[9] For example, the U.S. rainfall index product for forage and pasture insurance allows farmers to adjust the per acre expected value of forage at the county level by between 60 and 150 percent "to reflect the productivity of their own land." (USDA Risk Management Agency, 2009)

Under a weather rainfall index program, the farmer receives an indemnity when the weather index falls below its trigger value. The U.S. rainfall index program works as follows. In each grid, the expected average rainfall for the grid in the time period of interest is allocated an index value of 100. A farmer is allowed to purchase insurance by selecting a "coverage level" of between 70 and 90 percent of the index and receives an indemnity if the rainfall index value falls below the selected coverage level. The rainfall index value is constructed by dividing the actual rainfall in the grid during the insured period (as estimated by NOAA) by the expected or average rainfall for the grid. Thus, for example, the rainfall index has a value of 75 if rainfall is 75% of average and zero if no rainfall occurs. If a farmer selects a 90 percent coverage level and the rainfall index takes on a value of 75, then she will receive an indemnity. However, if she selects a 70 percent coverage level, then she will not receive an indemnity.

The indemnity schedule for a weather index or area yield index contract could be defined in several different ways. In all cases, no indemnity is paid when the index exceeds or equals its trigger value. When the realized index value is lower than its trigger value, the simplest approach is to make the indemnity a linear function of the difference between the trigger value and the index value. Suppose, for example, the expected area yield for a hectare of cotton in a valley in Northern Peru is 400kg and each kg of cotton is valued at $2. On a per hectare basis, the expected area revenue will then be $800. Letting V represent the expected area value of the crop, t the trigger value for a weather index, and r its realized value, as long as $t > r$, the producer receives a per hectare indemnity, I, such that:

(1) $I = (t - r) V.$

In this case, the maximum indemnity available to a farmer, also called the liability, is tV, the trigger value for the index multiplied by the expected area value of the crop. As long as t is less than 100 percent, at least notionally the contract involves a deductible as the farmer cannot insure at the full value of V.

Notation	
r =	the value of the index
t =	the trigger value of the index
I =	indemnity payment
V =	per acre value of the crop

For reasons that have never been fully explained, in the United States, the publicly provided rainfall and area yield index products have operated with a "declining deductible" indemnity schedule. Under this schedule, when the trigger value for the index exceeds the realized value, the declining deductible indemnity, I_d, is:

(2) $I_d = V \frac{(t-r)}{t}.$

As r becomes smaller, because $t < 1$, the ratio $(t - r)/t$ increases more rapidly than the expression $(t - r)$. When r equals zero, $(t - r)/t = t/t = 1$ and so $I = V$; in other words, the expected value of the crop becomes the maximum indemnity or liability under the contract. While this approach removes

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the deductible when losses are truly catastrophic, in practice, it is unlikely that either area yield based indexes or weather indexes will approach zero, even in semi-arid areas subject to extreme drought. So the difference between a linear and a declining deductible schedule might not appear to be too large.

In fact, the declining deductible approach does have potentially important consequences. First, it has the effect of increasing premium payments for any given premium rate as the liability under the contract is increased. It also increases indemnities at each realized value of the index under which indemnities are paid and, by implication, actuarially fair premium rates (premium rates that result in premium payments which equal expected indemnities). To see that this is the case, subtracting I from I_d, it follows that:

$$I_d - I = V\frac{(t-r)}{t} - V(t-r) = V\left\{\frac{(t-r)}{t} - \frac{t(t-r)}{t}\right\} = (1-t)V\left\{\frac{(t-r)}{t}\right\} = (1-t)I_d > 0.$$

Hence, the impact of the declining deductible schedule is to increase the actuarially fair premium payment by the proportion $(1-t)$ as all indemnities increase by that amount. For example, with a declining deductible payment schedule instead of a linear deductible schedule, a farmer who selects a 90 percent coverage level (t = 0.9) will have a ten percent higher actuarially fair premium payment while a farmer who chooses a lower coverage level of, say, 70 percent ($t = 0.7$) will have a 30 percent higher actuarially fair premium payment. Figure 1 illustrates the issue for a two hectare farm purchasing an index product in an area where the crop is valued at $500 per hectare, and the premium rate is 12 percent for the 90 percent coverage level and 10 percent for the 70 percent coverage level for both a declining deductible and linear indemnity schedule. At the 90 percent coverage level, the farm's premium payment will be $120 for the declining deductible contract (the liability of $1000 times the premium rate of 12 percent) but only $108 for the linear indemnity contact (the liability of $900 times the premium rate of 12 percent). At the 70 percent coverage level, the declining deductible premium payment will be $100 (the liability, which remains at $1000, times the premium rate of 12 percent) but the linear indemnity schedule premium payment will be $70 (because the liability falls to $700). The example indicates that poor households (are likely to purchase lower levels of insurance coverage because of cash flow and other constraints) may face much higher premiums under a declining deductible schedule than under a linear indemnity schedule and, therefore, be less likely to buy insurance if a declining deductible product is offered.

In countries where the governments subsidize actuarially fair premium rates so that a farmer's premium payment is less than the actuarially fair premium rate (for example, the United States and Canada), farmers will generally prefer a declining deductible contract because it increases the average subsidy they receive. Farmers who have to pay the full actuarially fair premium rate may or may not prefer a declining deductible depending on their risk preferences and the cost of other available risk management tools. Farmers who have to pay a loading factor for administration and operating costs that is proportional to the actuarially fair premium in addition to that premium are even less likely to prefer a declining deductible index-based contract.

Figure 1. Premium Payments For Declining Deductible and Linear IndemnityIndex Insurance

Another issue with the declining deductible schedule concerns its implications for a farm's revenues. Effectively, a declining deductible schedule guarantees that the farmer will receive the area average revenue in the event of a complete loss instead of a proportion of that revenue. However, if the area only incurs a small loss then even a farmer whose yields (or revenues) are identical to the area will receive an indemnity that provides her with only a portion of the area and her farm's average revenue, and effectively she will pay close to the full deductible. The larger the area (and farm's) losses, the closer will be farm revenues from indemnities and crop sales to the area average. There is no obvious policy justification for guaranteeing farmers higher total revenues from crop sales and indemnities when they have larger losses than when they have smaller losses. A linear indemnity schedule effectively guarantees the "average" farmer a constant share of her area's average revenue once losses occur, regardless of the severity of the area loss.

(iii). Premium Rates

Private insurance companies establish premium rates as follows. They estimate the expected or average indemnity that will be paid under the contract. The resulting amount is the *actuarially fair premium* or *pure risk premium*, A. They then include two other elements; a risk factor and an administration and operations (A&O) load. The risk factor, f, typically about 10 to 15 percent of the actuarially fair premium, is added to account for their uncertainty about their estimate of the expected indemnity.[10] The A&O load, L, is then added to account for administration and overhead costs associated with delivering and managing the insurance product as well returns to capital and adjustments for portfolio diversification effects.

The A&L load is also often expressed as a proportion, l, of the pure risk premium, A,; that is, $L = lA$. The total premium payment, P, is therefore:

$$(3). \qquad P = A + fA + L = (1 + f)A + lA = (1 + f + l)A$$

where $A + fA$ is the *risk adjusted actuarially fair premium rate*. In the USDA Risk Management Agency insurance programs, for example, actuarially fair premium rates are increased by about 13.6 percent to account for the risk associated with their estimation (that is; $f = 0.136$). Until recently (that is, until passage of the 2008 Farm Bill), U.S. agricultural insurance companies were also given 23.3 percent of the pure risk premium to cover A&O expenses and also expected to obtain an additional 10 percent of those premiums in underwriting gains. This implies a loading factor of 33.3% (that is; $l=0.333$). Currently, the A&O allowance permitted under the provisions of the 2008 Farm Bill is 18.6 percent, implying a loading factor 28.6 percent when expected underwriting gains are included. In the U.S. program, this loading factor is applied to the risk adjusted actuarially fair premium, $A + fA$, which

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[10] Estimates of expected indemnities are only statistical estimates and have their own statistical distributions (with associated standard deviations and other measures of dispersion). A risk averse insurance company (or a risk neutral insurance company concerned about over-fitting event distributions and underrating premiums) will therefore add in a "risk factor" charge to account for the down-side risk associated with their estimates of the potential distribution of the expected indemnity.

in fact increases the load as a proportion of the actuarially fair premium, *A*, to 32.5 percent. Generally, the A&O loading factor for commercial insurance does not include the risk factor, *f*.

Loading factors (relative to the pure premium, *A*) vary by line of insurance. Auto insurance in developed countries typically carries a loading factor of about 40 to 45 percent ($l = 0.4$ or 0.45) while commercial building and equipment insurance carries a loading factor of about 50 percent. The auto insurance example is important because some analysts have suggested that individual farm-based multiple peril insurance would carry risk and loading factors similar to those for auto insurance. If this is the case, then the ratio of the A&O expenses to the risk adjusted actuarially fair premium for purely privately offered multiple peril insurance would also be about 40 percent. Under the current standard reinsurance agreement for U.S. multiple peril and area yield programs, when underwriting gains are included, private insurers appear to be willing to accept a load that is about 30 percent of the estimated risk adjusted actuarially fair premium but, for several reasons, do not bear much risk of loss. At best, given marketing, indemnity distribution and other administrative costs associated with insurance sales to individual farmers, even index products are likely to involve a minimum loading factor of 25 percent.

(iv).   Timing Issues

Area yield index products are almost always offered on a growing season basis. Where double cropping takes place, area yields are adjusted to account for such production practices. Weather index products are different. Annual precipitation may be important in some regions and for some crops; growing season precipitation may be vital in other areas and for other crops; snow pack may be critical for livestock forage growth in high altitude and other colder semi-arid regions. Thus, with respect to timing, rainfall and other weather indexes should have very different designs in different settings, but care is needed in policy design to ensure that index products are linked to relevant events and actuarial sound. The U.S. Risk Management Agency's approach to rainfall index insurance, for example, has been problematic. The product divides the year into six two month intervals and calculates separate rainfall indexes for each period (USDA Risk Management Agency, 2009). A farmer is then required to insure no more than 70 percent of her planted area in any one index period and so must use two periods to insure all forage. This approach, however, is flawed in that it allows a farmer to game the product to maximize expected subsidies by insuring in intervals in which the rainfall index exhibits the most volatile behavior, regardless of whether rainfall in those periods has any direct link to crop yields or forage growth. Products offered in other countries have been more closely tied to either annual or growing season rainfall which (as discussed below) appear to be most relevant to crop yields and forage production.

Some private companies have developed extremely flexible products that allow a farmer to insure against multiple weather risks in multiple time periods. For example, some products allow a farmer to insure against crop yield and quality loss by insuring against the occurrence of too much hot weather (too many high degree days) during a critical part of the farmer's growing season, frost during

or just prior to harvest or crop germination, and lack of rainfall or too much rainfall during the growing season and/or harvest.

4.   Willingness to Pay (WTP) and the Demand for Crop Insurance: Empirical Evidence

Many analysts have claimed that the absence of purely private agricultural insurance products is the result of market failures resulting from systemic risk associated with correlated yield losses among farms (for example, because of drought or pest infestations).   Yet systemic risk is much more severe in markets for other types of insurance that are offered by the private sector (for example, hurricane insurance), as noted by Wright and Hewitt (1994) and Goodwin and Smith (1995 and 2009), among others. Markets for commodities may not exist, however, simply because the sellers' costs of providing a service are more than buyers are willing to pay.

(i)   Willingness to Pay Studies

To date, four studies have investigated the willingness of farmers to pay for crop insurance products using information on farm behavior. Two have focused on the willingness of farmers located in high risk, semi-arid regions of Australia to pay for either rainfall insurance (Bardsley, Abey and Davenport, 1984; Patrick, 1988) or multiple peril crop insurance products in which indemnities are tied to their own farms' losses (Patrick (1988). The other two studies have examined willingness to pay for rainfall index based crop insurance in two developing countries, Morocco (McCarthy, 2003) and Tanzania (Sarris et al (2006)). [11]

In 1986, in their seminal review of agricultural insurance programs targeted towards developing countries, Hazell, Pomereda and Valdes observed that "….the fact is that, with few exceptions, farmers in both developed and developing countries have been unwilling to pay the full cost of all-risk crop insurance" (Hazell et al (1986), page 7). The results reported in the three WTP studies completed since 1986, and the 1984 study by Bardsley, Abbey and Davenport, suggest that Valdes et al were prescient in their assessment. The methods used and results obtained in the four WTP studies are summarized in table 2.

These studies indicate that many farmers are not willing to pay the actuarially fair premium rate (that is, the pure risk premium rate) for either individual yield or rainfall index insurance. Sarris et al reported that many of the poorest farmers in Tanzania indicated that they simply could not afford to pay any insurance premiums (at least prior to harvest) because their cash flow situation was so dire

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[11] A fifth study on Willingness to Pay (WTP) for crop insurance in Australia by Fraser (1991) is frequently cited. However, this study is essentially a theoretical exercise that uses a mean variance framework to simulate WTP for farm level yield insurance under various assumptions about risk aversion and price and yield insurance. It does not account directly or indirectly for the availability of other risk management tools and so the estimates are almost surely maximum WTP estimates.   The range of WTP's reported is from about 111% to 150% of the actuarially fair premium, with the most plausible estimates being in the range o 111% to 130% (as the high end estimates assume an extreme degree of risk aversion).

and their incomes and wealth were so low. Similarly, McCarthy reported that Moroccan farmers with relatively high incomes were more likely to consider purchasing rainfall insurance than farmers with low incomes (quite possibly also because of cash flow problems). Nevertheless, even in a developed country context Patrick reported that more than 56 percent of the farmers in his sample were not willing to consider rainfall insurance, very few were willing to pay more than 110 percent of the actuarially fair premium, and almost no one would buy insurance if the load exceeded 20% of the actuarially fair premium.   The findings presented by Bardsley et al have similar implications. Their results indicate that a loading factor in excess of 5% is sufficient to deter private insurers from offering individual yield or index insurance because farmers simply wouldn't pay more than that amount.[12]

If, in fact, the private sector provision of an index product requires a 20 to 30 percent load, then the above evidence strongly suggests that rainfall index insurance is unlikely to be a sustainable option in countries where subsidies for agricultural insurance programs are unavailable. Further, in settings where governments or aid agencies can afford to subsidize all administrative and operations costs, many of the poorest farmers will still be unwilling to participate in voluntary insurance programs.

(ii).   The Demand for Crop Insurance

Most studies of the demand for crop insurance have focused on individual yield insurance (for example, Goodwin, 1992; Smith and Baquet, 1996; Smith and Goodwin, 1996; Goodwin and Smith 2003; and the survey by Coble and Knight, 1998), using data on actual insurance decisions either aggregated to the county level (Goodwin, 1992; Goodwin and Smith, 2003) or observations at the farm level (Smith and Baquet, 1996; Smith and Goodwin, 1996; Just and Calvin, 1993).   The general findings from these and other studies, which do provide general insights about why and when farmers buy agricultural insurance, are as follows.

First, almost all the studies of the demand for crop insurance have reported that higher premium rates (or lower expected returns, defined as the differences between expected indemnities and premium rates) result in substantially lower levels of participation in crop insurance programs (see, for example, Gardner and Kramer, 1986; Goodwin, 1992; Barnett, Skees and Hourigan, 1990; Niewoudt et al, 1985; Smith and Baquet, 1996; and Just, Calvin and Quiggin, 1999). Prior to 1980, for example, U.S. agricultural insurance products received relatively modest subsidies and participation rates were less than 20 percent. Premium subsidies were then increased in the 1980's and 1990's until, by 2001, farmers were on average paying only about 40 to 50 percent of the pure risk premium for coverage and participation rates grew to about 70% (Goodwin and Smith, 2009).

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[12] Quiggin (1986) has criticized the study by Bardsley et al, mainly on the grounds that they assume insurers are risk averse (and in some simulations as risk averse as the farmers they insure). But the general findings of Bardsley et al hold for insurers who are more than eight times less risk averse than the farmers they insure.

Table 2. Willingness to Pay Studies

Author(s)	Data	Methodology	Results
Bardsley, Abey, and Davenport (1984)	Yield data from 48 shires(countries) in New South Wales (Australia)	Supply and demand model for yield insurance, assuming an opportunity cost of self insurance against insolvency (bankruptcy) for farmers and varying degrees of risk aversion on the part of insurance sellers.	Maximum WTP for individual yield insurance is (implicitly) 5%. If loading factors for A&O exceed 5%, even an almost risk neutral insurer will sell no insurance contracts.
Patrick (1988)	Cross section sample of 60 wheat farmers in a high risk area of Australia (the Mallee River Valley in Victoria)	Direct elicitation of willingness to pay (WTP) estimates by farmers for farm level yield insurance and rainfall index insurance. Analyzed using Tobit regressions, sample means, and data enumeration.	Rainfall index insurance: 56% of the whole sample would not buy rainfall insurance with a 75% trigger. Given a loading factor of 10%, only 12% of farmers offered WTPs sufficient to cover that cost. Almost no farmer would pay a loading factor in excess of 20% Individual Yield Insurance: 25% of farmers would not buy 75% yield coverage, 50% would only pay the actuarially fair premium, and only 20% had a WTP that would cover a 10% loading factor.
McCarthy (2003)	Cross section data for farm households in 4 regions in Morocco with 48 households from each region	Probit and logit regression models estimated for three basic contracts (payments triggered when, relative to average rainfall at the nearby weather station, actual rainfall is first 50% or less, then 33% or less, and then 25% or less).	Median WTP estimates varied by contract and region, ranging from 96% to 117% of the actuarial fair value, but these estimates potentially overstate WTP because responders were constrained to consider only "take it or leave it" premium rate offers in contracts. For contracts with low premium rates, in responses to open ended questions, farmers generally stated lower WTPs than implied by the "take it or leave it" lower bound premiums.
Sarris, Karfakis, and Christiaensen (2006)	Data obtained from 957 households from 45 villages in the Kilimanjaro region (a relatively wealthy area) and 892 households from 36 villages in the Ruvuma region of Tanzania (the poorest area of Tanzania) interviewed in November of 2003 and November of 2004.	Probit regression models estimated for two types of rainfall index contract (indemnity paid when rainfall 10% below normal and indemnity paid when rainfall 30% below normal) and data enumeration.	Over 55% of all households surveyed would not purchase rainfall insurance at a positive premium. The average WTP was less than 50% of the actuarial fair premium for all contracts offered in both regions. Very few households had WTPs that exceeded the actuarially fair premium

Second, most studies have found considerable evidence of adverse selection. Farmers with more (less) volatile yields are likely to receive crop insurance indemnities more (less) frequently and in larger (smaller) amounts.[13] Thus, given they are offered the same premium rates (which tend to be set on area basis even for individual farm contracts), farmers with more volatile yields are more likely to buy insurance and farmers with less volatile yields are less likely to buy insurance. Both McCarthy (2003) and Sarris et al (2006) report that farmers located in regions where rainfall is less variable are less willing to pay for insurance (a related selection issue).

Third, at least in the United States, farmers with higher levels of debt are more likely to purchase crop insurance (Goodwin and Kastens (1995); Smith and Baquet (1996)). One explanation for this result is that lenders are requiring such farmers to purchase some form of agricultural insurance. However, farmers with high levels of debt may also choose to buy crop insurance because they face greater risks of insolvency and bankruptcy than other farmers. Interestingly, Atwood, Watts and Baquet (1996) have shown that, over time, farmers with agricultural insurance have incentives to increase their indebtedness precisely because the insurance program does protect them against insolvency and loss of their farm assets.

Fourth, the McCarthy and Sarris et al studies of willingness to pay for crop insurance in developing countries both reported that farmers with more education were more interested in rainfall insurance and willing to pay higher amounts. In a developed country context, Goodwin and Kastens (1993) and Smith and Baquet (1996) also found that farmers with more human capital were more likely to purchase crop insurance. One reasonable explanation for these findings is that more educated farmers are more likely to understand insurance products. A second explanation is that, especially in a developing country context, farmers with more human capital are also less constrained in their risk management decisions by cash flow concerns because their households have higher incomes and wealth.

The findings of these studies of crop insurance demand and participation therefore suggest that agricultural insurance programs are likely to be more successful in environments where yields are more volatile, farmers are better educated, debt is a concern, and premium rates are subsidized. Not all of these conditions are met for regions in which farm households are "the poorest of the poor."

5.   **Basis Risk**

In the world of insurance, one of the worst outcomes for an insured entity is to have a loss that is not indemnified because it is not covered under the terms of the insurance contract, even though the entity purchased the insurance with the intent of protecting itself against that type of loss.

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[13] In an early study of participation in the U.S. crop insurance program by California farmers raising irrigated cotton, Zering et al (1987) reported that almost none of the farmers in their sample purchased insurance against yield loss because their annual yields almost never fell below 90 percent of their longer run average yields.

Householders whose homes have been serious damaged by water are often horrified to discover that they are not covered for flood damage, but only for water damage arising from other types of events like faulty plumbing.   Similarly, farm households who purchase agricultural insurance generally want to receive indemnities when they experience losses on their own farms.   Index insurance does not guarantee that farmers will get an indemnity when they experience an "on-the-ground" loss; nor does it guarantee that if they do receive an indemnity check, the size of the check will be commensurate with the losses the farmers incur. Moreover, some farmers will be indemnified when they have incurred no losses.

This problem, described as basis risk by Miranda, has been widely acknowledged by almost all proponents and analysts of index insurance (see, for example, Mahul, 1999; Miranda and Glauber, 1997; Skees et al, 2007; and Smith at al, 1994). However, there is considerable disagreement about the size and scope of the problem.   There is also some confusion about differences among insurance index products when it comes to basis risk.   Research has been carried out on the correlation between three types of indexes and farm yields: rainfall indexes, vegetation (NDVI) indexes, and area yield indexes.   Several analysts have suggested that these correlations can be relatively large and, therefore, that weather and area yield index products can be an effective and desirable risk management tool for farmers (for example, Vedenov and Barnett, 2004).

The evidence on correlations between even area yields or satellite measures of plant growth and farm yields is a genuine concern.[14] Both Miranda (1991) and Smith et al (1994) found that many farmers would have to heavily over-insure their crops to obtain income smoothing similar to that obtained from an individual yield contract. Smith at el showed that for actuarially fair contracts (in which premiums equal expected indemnities) premium payments for those farmers would be very substantial relative to the value of the crops insured. In a developing country context, such premiums (which could amount to more than 50 percent of the expected value of a crop in extreme cases and over 20 percent in many cases) would be prohibitive.

The correlation between precipitation (the most commonly proposed basis for weather indexes) and farm yields are likely to be much smaller. Correlations between precipitation and either plant biomass growth, or forage, or crop yields have been examined by several ecologists, range scientists, and agronomists. The findings of those studies, summarized in table 3, are generally not encouraging for insurance products that rely on rainfall indexes. Precipitation effects on forage and grass production in a wide variety of ecological settings (including semi-arid and near desert environments) throughout North America, South America, Africa and some other sites have been examined by Duncan and Woodmansee (1975), Khumato and Holechek (2005), Murphy (1970), Pumphrey (1980), Sims and Singh (1978), Scurlock and Olsen (2002), Price et al (1998), and Jogaby and Sala (2000).

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[14] Frank and Karn (2003) reported that the maximum correlation they could find between an NDVI index for a 12 by 12 kilometer grid index and biomass on the ground was 0.8. Given that the linkage was with biomass production, not crop production, and that a reasonable estimate of correlations between individual farm yields in relatively dry areas is about 0.6, at best the correlation between the vegetation index and a typical farm's yields is likely to be about 0.48.

Table 3. Precipitation and Weather Station Yield Correlations

Author	Crop	Region	Correlation
Duncan and Woodmansee	Forage	California	0.67
Klages	Wheat	Idaho	0.40
Khumalo and Holechek	Grass	New Mexico	0.82
Jobbagy and Sala	Grass and shrubs	Patagonia	0.59 (annual rainfall) 0.80 (winter rainfall)
Martyniak	Barley	Poland	0.46
	Wheat	Poland	0.53
	Triticale	Poland	0.47
Murphy	Forage	California	0.70
Prince et al	Forage	Sahel, Africa	0.70 (all sites) 0.27 (low rainfall sites)
Pumphrey	Herbage and Grass	Oregon	0.33
Scurlock and Olsen	Biomass (from NDVI data)	30 plus global sites	0.56
Sims and Singh	Grassland	Western North America	0.30
Staggenborg et al	Corn	Kansas and Nebraska	0.56
	Grain Sorghum	Kansas and Nebraska	0.45

Correlations between precipitation and biomass growth at the weather station (or, in one case, NDVI measures) reported by these studies range from 0.26 (for low rainfall sites in the Sahel area of Africa) to a maximum of 0.8 (for grasses in New Mexico) and average about 0.6. Studies of the link between rainfall indexes and crop production at or relatively close to weather stations by Klages (1941), Martyniak (2007), and Staggenborg et al (2008) have reported lower correlations that range from 0.46 (for corn in Kansas and Nebraska) to 0.53 (for wheat in Poland). The above evidence suggests that the assumption of a correlation coefficient of 0.7 between plant growth at a weather station and precipitation at the station would be relatively optimistic.

Assuming farms have identical variances implies that the correlation between precipitation at a weather station and yield at farm k, which is not located at the station, is simply $r_{pk} = r_{pj}r_{jk}$, where j identifies the farm at the weather station site and r_{pj} is the correlation between precipitation at the weather station and yield at the farm on which the weather station is located (see Appendix A for the mathematical details of the argument). This suggests that if the correlation between precipitation and yield at the weather station is 0.7 and the correlation between yields among farms is 0.50 (about 0.7^2) then the correlation between the precipitation index and the typical farm's yields would be 0.35. This does not imply there is a "very close" relationship between precipitation indexes and individual farms' actual yield outcomes. The policy question is whether such relationships are good enough.

A single contract is considered in which indemnities are triggered when precipitation is less than 70 percent of normal. The primary basis risk concern is whether a farm will receive an indemnity when it incurs an "on-the-ground" loss and what the size of the indemnity will be. Thus, for each assumed correlation between the rainfall index and the area yield, ten thousand random draws are used to construct probabilities of indemnification for losses when a farm experiences different yield outcomes.

Three indemnity probability estimates for each assumed rainfall index-area yield correlation coefficient are developed for farmers who experience three alternative yield scenarios. The three yield scenarios are as follows:

- Severe yield losses: a farm is assumed to experience *very low yields* and severe losses when its actual yield falls below 50 percent of its average.
- Significant yield losses: a farm is assumed to experience *low yields* and significant losses when its yields fall between 50 and 70 percent of its average.
- High yields: a farm experiences above average yields.

The third scenario is included to indicate the likelihood of a "Type 2" error, the farmer is assumed to have a loss and to need an indemnity payment when in fact she does not need that payment. The three indemnity outcomes for which probabilities are computed in each yield scenario are:

- *No indemnity* is paid.
- A *small indemnity* is received (an indemnity payment is low if rainfall is between 50 and 70 percent of normal).
- A *large indemnity* is received (an indemnity payment is large if rainfall is below 50 percent of normal).

Simulation results are presented in table 4-6. Table 4 includes indemnity probability estimates for the scenario in which farm yield losses are severe (less than 50 percent of normal).   If the correlation coefficient between the rainfall index and a farm's yield is 0.6 (at the high end of the likely range implied by the estimates presented in table 3), then if that farm has a severe yields loss it has a 36.2 percent probability of receiving no indemnity, and a 24.3 percent probability of receiving a small indemnity. The probability that the farm will receive a large indemnity is only 39.5 percent. The situation is somewhat improved if the correlation coefficient between the rainfall index and farm yields is 0.8 (at the highest end of the range reported in table 3), but there is still 16 percent probability that farms with severe losses will receive no indemnities and a 24.7 percent probability that they will only receive a small indemnity.   In fact, the correlation between the rainfall index and a farm's yields would have to reach 0.9, before farms with severe yield losses have 90 percent or better probability of being indemnified.

The results presented in table 5 indicate that farmers who experienced significant yield losses (yields between 50 and 70 percent of normal) have a 60 percent probability of not being indemnified if the rainfall index-farm yield correlation coefficient is 0.6, although they also have a 20 percent probability of receiving a large indemnity.   Further, even if the correlation coefficient were to increase to 90 percent, those farmers would still have a 27 percent probability of not receiving an indemnity. Finally, table 6 shows how farms with above average yields fare. If the rainfall index-farm yield correlation coefficient is 0.6, then farmers have a 2.3 percent probability of receiving a large indemnity and a 5.7 percent probability of receiving a small indemnity.

The empirical evidence on rainfall index-plant growth correlations presented in table 3, coupled with the results of the Monte-Carlo simulations presented in table 4-5, tell a compelling story. Basis risk is substantial for these indexes and "livelihood insurance" products based solely on them are unlikely to be of much benefit to many individual farmers at the times when they most need help. Absent substantial subsidies, insurance products targeted to individual farmers would need to be much more closely correlated with their individual yields. The question, therefore, is what those weather index products would look like and whether adequate data be available to support their development and sustained provision.   Alternative approaches might combine rainfall data with other weather information or satellite data and other information on area yields. However, such products are currently not in the public domain and may not even be feasible in most developing countries because of lack of data on area yields.

Table 4. Indemnity Payment Outcomes for Farmers Experiencing Severe Yield Losses
(yields less than 50 percent of average)

Rainfall Index-Area Yield Correlation	Probability of Indemnity Event		
	No Indemnity	**Small Indemnity** [A]	**Large Indemnity** [B]
0.00	0.777	0.123	0.100
0.20	0.671	0.155	0.174
0.40	0.526	0.206	0.268
0.60	0.362	0.243	0.395
0.80	0.168	0.251	0.580
0.90	0.067	0.247	0.686
0.95	0.024	0.199	0.777
1.00	0.000	0.000	1.000

A.   A small indemnity is an indemnity paid when the rainfall index has a value of between 50 and 70 percent.

B.   A large indemnity is an indemnity paid when the rainfall index has a value of less than 50 percent.

Table 5. Indemnity Payment Outcomes for Farmers Experiencing Significant Yield Losses (yields between 50 and 70 percent of average)

Rainfall Index-Area Yield Correlation	Probability of Indemnity Event		
	No Indemnity	**Small Indemnity** [A]	**Large Indemnity** [B]
0.00	0.784	0.114	0.103
0.20	0.723	0.145	0.132
0.40	0.661	0.179	0.159
0.60	0.590	0.219	0.192
0.80	0.479	0.316	0.205
0.90	0.377	0.429	0.194
0.95	0.278	0.559	0.163
1.00	0.000	1.000	0.000

A.   A small indemnity is an indemnity paid when the rainfall index has a value of between 50 and 70 percent.

B.   A large indemnity is an indemnity paid when the rainfall index has a value of less than 50 percent.

Table 6. Indemnity Payment Outcomes for Farmers Experiencing Above Average Yield Losses

Rainfall Index-Area Yield Correlation	Probability of Indemnity Event		
	No Indemnity	Small Indemnity A	Large Indemnity B
0.00	0.774	0.119	0.107
0.20	0.820	0.103	0.077
0.40	0.867	0081	0.051
0.60	0.921	0.057	0.023
0.80	0.972	0.025	0.003
0.90	0.993	0.006	0.001
0.95	0.999	0.001	0.000
1.00	1.000	0.000	0.000

A. A small indemnity is an indemnity paid when the rainfall index has a value of between 50 and 70 percent.

B. A large indemnity is an indemnity paid when the rainfall index has a value of less than 50 percent.

The potential for weather index insurance to improve the ability of farmers to repay debt is clearly linked to basis risk. In fact, the potential of agricultural insurance to improve poor farmers' access to financial capital is a major reason for the widespread policy interest that weather index insurance has attracted. The argument that insurance provides insured entities with greater capacity to carry and service debt can be formalized as follows. Suppose that a collateralized loan to a farmer is made by a financial institution, there is no likelihood of moral hazard or fraud by either party, and that the collateral will become the possession of the lender (up to the value of the loan balance which may exceed the values of the collateral because of accumulated interest) if loan payments are not made. The interest rate on the loan includes two components: (1) the cost of the use of risk free capital, and (2) a risk component that compensates for the possibility of failure to recover the full value of the loan balance from recovered collateral if the borrower has to default on the loan. Now suppose that a "perfect" insurance instrument for loan payment default is acquired with no transaction costs; that is, if the loan repayment cannot be made by the insured individual, there is no basis risk and the insurance indemnity will equal the required payment. In these circumstances, the risk component of the interest rate will become zero but the insurance premium will equal the interest rate risk charge that would be made by the lender in the absence of insurance. If the insurance instrument is less than perfect, because of basis risk, then the interest rate on the loan will continue to include a risk component. Further, if the insurance premium includes a transactions charge, a requirement that insurance be purchased will increase the cost of the loan to the farmer and the farmer's ability to handle debt could be reduced.[15]

Basis risk may be much less important if the goal is to enable entities which provide loans to poor farmers to have access to insurance against systemic loan defaults on the part of those farmers. However, in-country political support for programs that appear to directly benefit relatively large and wealthy banks and agri-businesses, or even more modest microfinance operations, rather than poor farmers may be limited.

6. Scalability and Sustainability of Weather and Other Index Insurance Products

So far, in developing countries, almost all weather and area yield insurance products have been offered on a pilot basis to relatively small numbers of farmers. For example, the BASIX

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[15] In a typical insurance context, an indemnity payment is made when insured entities (farms) experience losses while, in similar circumstances, financial lending institutions would initiate loan collection efforts that could result in the borrower losing their collateral (farm). However, in the longer term, if the borrowers' non-indemnity funds are insufficient to cover loan payments, then insurance will not be available (or become too expensive) and borrowers will still lose their collateral. Of course, short term defaults on loans may be covered in alternative ways (for example, through refinancing) because foreclosures are costly. Thus refinancing has broader implications for the lender while an indemnity payment is "normal" business for insurance companies.

index insurance products offered in India have been purchased by about 10,000 farmers. While this may seem like a larger number, it is a second or third order decimal percentage point in terms of the millions of low income farm households who raise crops like wheat and cotton in that country. Proposals for weather indexed based livelihood insurance products in countries like Peru and Vietnam are also targeted to relatively small areas and small numbers of households. Two central questions for any pilot program, therefore, are (1) whether or not the program can be scaled up to meet the needs of all, or at least most, similarly situated farmers in a country and (2) whether, once scaled up, the program can be sustained over the long term.

These questions are important for several reasons. First, on an ethical basis, if a program systematically benefits some people but not others who are similarly situated, why is that group to be so favored. A reasonable short run answer (and a standard response in the context of the ethics of testing new medical treatments) is that the effectiveness of the program needs to be understood, some people have to be "guinea pigs," and those "guinea pigs" have been selected (somewhat) randomly. That is not a long run answer and if the insurance program (or medical treatment) is not made available under basically the same conditions to all people reasonably quickly then there is a serious ethical problem. Second, that sort of ethical problem soon translates into a political problem; a program that benefits the few but not the many will be politically unpopular, with corresponding consequences for the government, aid agency, or insurance company managing the program. Third, where the goal is to benefit the poorest of the poor, if a program to accomplish that goal is viable, then it should be scaled up.

Several conditions must exist for an insurance product to be scaled up to a regional or national level. These necessary conditions are as follows.

First and perhaps foremost, *a substantial number of potential users of the insurance product must be willing to use it*. In the case of agricultural insurance products targeted to farmers, the farmers have to be willing to buy the product. The current evidence about willingness to pay indicates that a majority of low income farmers in developing countries are not currently willing to pay an actuarially fair (pure risk) premium for rainfall insurance. Further, most of the farmers who are willing to pay that amount are not willing to pay much more, and certainly not enough to cover the A&O expenses that would be incurred by private insurers.

Early (and even more recent) studies of weather index insurance argued that A&O costs of providing index insurance to farmers would be very small, in the order of 2 to 5 percent of the pure risk premium (see, for example, Halcrow, 1949; Quiggin, 1986; and Fraser, 1992), because, unlike individual farm insurance products, index insurance did not involve the need for monitoring moral hazard and fraud. However, those studies failed to adequately recognize that, at a minimum, insurers would have to identify each farm's liability and coverage levels; record, store, and retrieve data on each insured farm's and farmer's location; determine eligibility for program participation; and, when indemnities were due, make indemnity payments. The latter

task might appear to be a simple one, but could be much more complex in a developing country context than simply mailing a check to the insured. In addition, regardless of the line of insurance involved, most private primary insurance companies seek to offload some of the risk associated with their insurance portfolio to reinsurers and they can only do so at a further cost. These A&O and reinsurance costs are likely to amount to at least 25 to 30 percent of the actuarially fair premium rate even for an index product.

Second, therefore, it seems likely that, if farmers are to use index products on large scale and over a sustained period, *some means for substantially reducing or eliminating the A&O component of the total premium will have to be identified*. One way to reduce costs may be to "piggy back" or bundled index insurance products with other goods or services farmers need that already require the collection of much of the data on farms and farm operations that would otherwise be required.   Hence, several proposals have been put forward for linking index insurance to sales of agricultural inputs like fertilizer or to loans.   Those approaches would reduce A&O costs but would not eliminate them. The evidence from the U.S. experience with crop insurance is that when only the A&O cost is subsidized, participation in individual yield programs is less than 20 percent. Further, evidence from the WTP studies based on data from Tanzania and Morocco imply that participation in a weather index program would be no better (and probably worse) if only the A&O costs of the insurance were subsidized or reduced to close to zero by creative bundling.

Third, one barrier to the use of agricultural insurance for very poor farm households is that *those low-income households face cash flow or liquidity constraints* that inhibit their ability to pay premiums before harvest (McCarthy; Sarris et al).   However, if insurers allow those households to delay their premium payments until after harvest, then (especially in years where no losses occur and no indemnities are to be paid) the insurers face the problem of collecting premiums from those farm households (who are still very poor and need every penny they can find to keep body and soul together).   A potential solution to this problem would be for the government to guarantee the premiums, but, in the end, this would almost surely amount to a subsidy program as the government would also be faced with the challenge of collecting the premiums from the farmers.

Fourth, *basis risk is a central concern that has to be effectively addressed*. As discussed in section 2 and section 5, farmers are reluctant to purchase insurance products that do not always provide indemnities when they experience crop losses or crop revenue losses. However, the smaller the area to which an index-based insurance product applies, the less serious will the basis risk. Thus, to be scalable, an index-based product has to be developed for small (and perhaps very small) geographic areas.   For rainfall indexes, as the simulations presented in section 5 suggest, the area served may have to be a township or even a sub-township area before indemnities become sufficiently closely correlated with losses for most farm households. Alternatively, weather indexes may have to be combined with other indicators of yields within

an area (for example, area yields and satellite data on plant growth) to create indexes that are sufficiently closely correlated with farm yields.

Fifth, a necessary condition for the provision of insurance is the *in-country capacity to deliver the insurance program*. Skees et al, for example, have focused on the need for a regulatory environment in which index insurance is recognized by insurance regulators as insurance and not gambling. (Some insurance regulators view the purchase of index-based insurance as closer to the purchase of financial derivatives or stocks and bonds, and therefore not subject to their purview.) While this is one concern, it is not the only, or even the most important capacity issue. Skees et al, and others, have also identified the need for an appropriate legal framework. However, that is also not enough. Capacity involves the development of *sufficient human capital to do the job*; in other words, in the context of agricultural insurance, a reliable infrastructure for the delivery and regulation of agricultural insurance is required before insurance products can be scaled up for full regional or national delivery.

For example, initial attempts by the World Bank and others to establish an agricultural insurance program in Ukraine over the period 2001-2004 foundered in part because of a lack of trained private and public sector personnel to develop and regulate the agricultural insurance products that were being introduced, and to manage the subsidies allocated to the program by the government of Ukraine. It seems likely that agricultural insurance pilot programs in many other settings have not been scaled up for precisely this reason: there was no, or insufficient in-county capacity to deliver and regulate the program.

Sixth (and last but by no means least), *agricultural insurance programs that are not solely guaranteed by the government must be structured to be acceptable for reinsurance* by major reinsurance companies. Almost no primary agricultural insurers in developed countries have sufficient liquidity to cover catastrophic losses associated with systemic risk, even though governments in those countries provide stop loss guarantees (as is the case in the United States through the USDA RMA Standard Reinsurance Agreement). So they off-load much of that risk to international private reinsurance companies. This means that those reinsurers have to be willing to accept the risks they are offered. Two fundamental conditions have to be satisfied for this to be the case. First, *the agricultural insurance products have to be actuarially sound from the reinsurer's perspective*. This means that the sum of guaranteed government subsidies and premiums paid by farmers must be sufficiently large to cover all A&O costs and expected indemnities. Second, *the program must be politically sound*: that is, the reinsurers have to believe that governments will not pressure primary insurers to pay for losses when, in fact, under the terms of the insurance contract, farmers are not eligible for indemnities. In many developing country settings, this is a real concern for index insurance as well as individual farm-based multiple peril insurance. Basis risk inevitably implies that, under index insurance, many farmers will not be paid an indemnity when they have actually experienced losses and those farmers are likely to protest about the situation. It is often difficult for some governments with limited resources to ignore such protests, and they may perceive that one way out is to bring political

pressure to bear on insurers to pay claims or to blame the insurers for the "failure" of their product. In either case, reinsurers are likely to be reluctant to sustain a long run commitment to the agricultural insurance program, or even make initial commitments to reinsure such programs.

7.   Conclusion

Scalability and sustainability are critical for the successful long run implementation of agricultural insurance programs, including weather index products. This review has indicated that basis risk and farmers' willingness to pay for agricultural insurance products are key determinants of whether unsubsidized voluntary agricultural insurance programs can be successfully scaled up and sustained. Weather index insurance products, as currently constituted, appear to involve substantial basis risk for many farmers. So it is not surprising that willingness to pay studies have consistently reported that many farmers in both developed and developing counties have limited interest in such products. In fact, a majority of farmers are not even willing to pay an actuarial fair or pure risk premium to obtain coverage under rainfall index products and very few are willing to the 25 to 30 percent loading factors that are probably needed to ensure product delivery. Very poor farmers have also indicated that one important barrier to access is their cash flow/net worth situation prior to harvest that prohibits them from paying any premiums.

These findings have several important implications. The first is that better indexes are needed if weather index insurance is to be successful; indexes that have less than an 85 to 90 percent correlation with crop and forage yields are unlikely to deliver indemnities that are commensurate with farmers' crop losses on a reliable basis.   Many rainfall indexes appear to have correlations with farm yields that are less than 50 percent, even if farms are within 20 to 50 kilometers of the weather stations on which the indexes are based.

The second important implication is that, even if indexes are closely correlated with crop losses, almost all farmers are still not willing to pay the required A&O loading factors. So, either new, very low cost delivery mechanisms have to be developed (perhaps through bundling the insurance with other services) or A&O costs have to be subsidized by some entity (the government, international aid agencies, etc.). Even then, the historical evidence from countries like the United States, Canada, and India suggests that participation rates would be less than 20 percent. Higher participation would have to be "purchased" by additional subsidies and where the funds for those subsidies could be found is a difficult question for developing country governments.

Finally, there is a "third way" for an agricultural insurance programs to resolve the scalability problem: to make the purchase of weather index products (or any other agricultural insurance) mandatory at either the pure risk premium or a loaded premium. This would certainly resolve the scalability problem in the short run. However, the long run sustainability of a

mandatory program whose costs are perceived to outweigh its benefits by a majority of farmers is debatable, especially in democracies.

References

Atwood, Joseph A., Myles J. Watts, and Alan E. Baquet (1996). "An Examination of the Effects of Price Supports and Federal Crop Insurance upon the Economic Growth, Capital Structure, and Financial Survival of Wheat Growers in the Northern High Plains." *American Journal of Agricultural Economics*; 78(1): 212-24.

Barnett, B. J., J. R. Skees, and J. D. Hourigan. "Examining Participation in Federal Crop Insurance." Staff Paper No. 275, Department of Agricultural Economics, University of Kentucky.

Bourgeon, Jean-Marc, and Robert G. Chambers. "Optimal Area Yield Insurance Reconsidered." *American Journal of Agricultural Economics*; 85(3): 590-604.

Bardsley, Peter, Arun Abey and Scott Davenport (1984). "The Economics of Insuring Crops Against Drought." *Australian Journal of Agricultural Economics*; 28(1): 1-14.

Carter, Michael R. (2009). "Potential and Pitfalls of Index Insurance." Presentation to the Bill and Melinda Gates Foundation, Seattle.

Chambers, Robert G., and John Quiggin (2002). "Optimal Producer Behavior in the Presence of Area-Yield Insurance." *American Journal of Agricultural Economics*; 84(2): 320-334.

Duncan, Don. A., and Robert. G. Woodmansee (1975). "Forecasting Forage Yield from Precipitation in California's Annual Rangeland." *Journal of Range Management*; 28(4): 327-249.

Frank, A. B., and J.F. Karn (2003). "Vegetation Indices, CO_2 Flux, and Biomass for Northern Plains Grassland." *Journal of Range Management*: 56 (3): 382-387.

Fraser, Rob (1992). "An Analysis of Willingness-to-Pay for Crop Inurance." *Australian Journal of Agricultural Economics* 36(2): 83-95.

Gardner, B. L. and R. A. Kramer. "Experience with Crop Insurance Programs in the United States." In *Crop Insurance for Agricultural Development: Issues and Experience*, Johns Hopkins University Press, Baltimore.

Goodwin, B. K. and Terry L. Kastens (1993). "Adverse Selection, Disaster Relief, and the Demand for Multiple Peril Crop Insurance." Research Report to the Federal Crop Insurance Corporation, Kansas State University.

Goodwin, Barry K., and Vincent H. Smith (1995). *The Economics of Crop Insurance and Disaster Relief*. AEI Press, Washington, D.C.

Goodwin, Barry K., and Vincent H. Smith. (2003) "An Ex-Post Evaluation of the Conservation Reserve, Federal Crop Insurance, and other Government Programs: Program Participation and Soil Erosion." *Journal of Agricultural and Resource Economics*, 28(2): 201-216

Goodwin, B.K., and V. H. Smith. (2009). "Private and Public Roles in Providing Agricultural Insurance in the United States" in Jeffrey Brown, editor, *Public and Private Roles in Insurance*, AEI Press, Washington, D.C., forthcoming.

Halcrow, Harold G (1949). "Actuarial Structures for Crop Insurance." Journal of Farm Economics; 31(3): 418-443.

Hazell, Peter, Carlos Pomerada, and Alberto Valdes (1986). *Crop Insurance for Agricultural Development: Issues and Experience.* Johns Hopkins University Press, Baltimore.

Hojjati, B. and N. E. Bockstael. "Modeling the Demand for Crop Insurance." In *Multiple Peril Crop Insurance: A Collection of Empirical Studies.* Ed. H. Mapp. Southern Cooperative Series Bulletin No. 334, pp. 153-76.

Jobbagy, E. G., and O. E. Sala (1998). "Controls of Grass and Shrub Aboveground Production in the Patagonian Steppe." *Ecological Applications;* 10(2): 541-549.

Just, Richard E., and Linda Calvin (1993). "Moral Hazard in U.S. Crop Insurance: An Empirical Investigation." Unpublished Manuscript, University of Maryland.

Just, Richard E., Linda Calvin, and John Quiggin (1999). "Adverse Selection in Crop Insurance: Actuarial and Asymmetric Information Incentives," *American Journal of Agricultural Economics* 81(4): 834-849.

Khumato, Godfrey and Jerry Holechek (2005). "Relationship between Chihuahuan Desert Perennial Grass production and Precipitation." *Rangeland Ecology and Management*; 58(3): 239-246.

Karl H. Klages (1942). *Ecological Crop Geography*. McMillan and Company, London.

Knight, Thomas O., and Keith H. Coble. "A Survey of Literature on U.S. Multiple Peril Crop Insurance Since 1980." *Review of Agricultural Economics.* 19(1997): 128-156.

Kramer, Randall A. (1983). "Federal Crop Insurance: 1938-82," *Agricultural History*, 57, pp 181-200.

Mahul, Olivier (1999). "Optimal Area Yield Insurance." *American Journal of Agricultural Economics*; 81(1): 75-82.

Mahul, Olivier, and Jerry Skees (2006). "Piloting Index-Based Livestock Insurance in Mongolia." *AccessFinance*; Issue 10: 1-4.

Martyniak, Ludwika (2007). "Response of Spring Cereals to a Deficit of Atmospheric Precipitation in the Particular Stages of Plant Growth and Development." *Agriculture Water Management*; 95 (3): 171-178.

Miranda, Mario J. (May 1991). "Area-Yield Crop Insurance Reconsidered," *American Journal of Agricultural Economics*, 73(2), pp 233-242.

Miranda, Mario J., and Joseph W. Glauber (1997) "Systemic Risk, Reinsurance, and the Failure of Crop Insurance Markets." *American Journal of Agricultural Economics*, 79(1), pp. 206-15.

McCarter, Nancy (2003). "Demand for Rainfall-Index Based Insurance: A Case Study from Morocco." IFPRI Environmental and Production Technology Division Working paper Number 106, Washington D.C.

Murphy, Alfred H. (1970) "Predicted Forage Yield Based on Fall Precipitation in California Annual Grasslands." *Journal of Range Management*; 23(4): 363-365.

Nieuwoudt, W. L., S. R. Johnson, A. W. Womack, and J. B. Bullock. "The Demand for Crop Insurance." Agricultural Economics Report No. 1985-16, Department of Agricultural Economics, University of Missouri.

Patrick, George E. (1988). "Mallee Wheat Farmers' Demand for Crop Insurance," *Australian Journal of Agricultural Economics*; 32(1), pp 37-49.

Prince, S. D., E. Brown de Coltound, and L. L. Kravitz (1998). "Evidence from rain use efficiencies does not indicate extensive Sahelian desertification." *Global Change Biology*; 4: 359-374.

Pumphrey, F. P. (1980) "Precipitation, Temperature and Herbage Relationships for a Pine Woodland Site in North-eastern Oregon." *Journal of Range Management*; 33(4): 307-310.

Quiggin, John (1988). A Note on the Variability of Rainfall in the Viability of Rainfall Insurance." *Australian Journal of Agricultural Economics*; 30(1): 63-69.

Sarris, Alexander, Panayoiotis Krfakis, and Luc Christiaensen (2006). "Producer Demand and Welfare Benefits of Rainfall Insurance in Tanzania." FAO Commodity and Trade Policy Working paper Number 18, Rome.

Scurlock, J. M. O., and R. J. Olsen (2002). "Terrestrial net primary productivity – A brief history and a new worldwide data base." *Environmental Reviews*; 10: 91-109.

Sims, P. L., and J. S. Singh (1978). " The Structure and Function of Ten Western North American Grasslands:. Intra-seasonal Dynamics and Primary Producer Compartments." *Journal of Ecology*; 66: 547-572.

Skees, Jerry, Jason Hartell and Anne G. Murphy (2007). "Using Index-Based Risk Transfer Products to Facilitate Micro Lending in peru and Vietnam." GlobalAgRisk Inc. unpublished working paper.

Skees, Jerry (2008). *Innovation in Catastrophic weather Insurance to Improve the Livelihoods of Rural Households*. Proposal submitted to the Bill and Melinda Gates Foundation.

Smith, Vincent H, and Barry K. Goodwin (1996). "Crop Insurance, Moral Hazard, and Agricultural Chemical Use." *American Journal of Agricultural Economics*; 78(2): 428-438.

Smith, Vincent H, and Alan Baquet (1996). "The Demand for Mulitple Peril Crop Insurance: Evidence from Montana." *American Journal of Agricultural Economics*; 78(1): 75-83.

Smith, Vincent H., Hayley H. Chouinard, and Alan Baquet. "Almost Ideal Area Yield Crop Insurance Contracts." *Agricultural and Resource Economics Review*; 23(1): 250-261.

Staggenborg, S. A., K. C. Dhuyvettere, and W. B. Gordon (2008). "Grain Sorghum and Corn Comparisons: Yield, Economic and Environmental Responses." Agricultural Experiment Station Working Paper, Kansas State University, Manhattan, Kansas.

Turvey, Calum (2001). "The Pricing of Degree Day Weather Options." Department of Agricultural Economics and Business Working Paper 02/05, University of Guelph, Ontario, Canada.

USDA Risk Management Agency (2009). "Pasture, Rangeland, Forage Pilot Insurance Program." Program Aid Fact Sheet Number 1896.

Vedenov, Dmitry V., and Barry J. Barnett (2004). "Efficiency of Weather Derivatives as Primary Crop Insurance Instruments." *Journal of Agricultural and Resource Economics*; 29(3): 387-403.

Wright, Brian D., and Julie A. Hewitt (1994). "All Risk Crop Insurance: Lessons from Theory and Experience." In Darell L. Hueth and William H. Furtan, *Economics of Agricultural Crop Insurance: Theory and Evidence*; 73-109, Kluwer Academic Publishers, Boston.

Zering, Kelly D., Chester O. McCorkle, and Charles V. Moon (1987). "The Utility of Multiple Peril Crop Insurance fir Irrigated Multiple Crop Agriculture." *Western Journal of Agricultural Economics*; 12(1): 50-59.

Appendix A: A Technical Note on Yield and Precipitation Correlations That Have Implications for Basis Risk

The correlation between precipitation in an area, the area yield and a farm yield in the area can be investigated as follows. Let all farms have identical yield means and variances and let:

x_{tj} = farm yield (mean adjusted) for farm j in year t,

A_t = area yield (mean adjusted) in year t = $\frac{\Sigma_j x_{tj}}{J}$,

v_{tj}= farm deviations in year t for farm $j = x_{tj} - A_t$,

where $\Sigma_t v_{tj} = \Sigma_j v_{tj} = 0$.

The farm yield – area yield correlation coefficient is therefore:

$$r_{A\,x} = \frac{\Sigma_t \Sigma_j x_{tj} A_t}{\sqrt{\Sigma_t \Sigma_j x_{tj}^2}\sqrt{\Sigma_t \Sigma_j A_t^2}} = \frac{\Sigma_t \Sigma_j (A_t + v_{tj})A_t/(TJ)}{\sigma_x \sigma_a}$$

Note that,

$$\Sigma_t \Sigma_j v_{tj} A_t = \Sigma_t (A_t \Sigma_j v_{tj}) = 0.$$

Thus,

$$r_{A\,x} = \frac{\Sigma_t \Sigma_j A_t^2/(TJ)}{\sigma_x \sigma_a} = \frac{\sigma_A^2}{\sigma_x \sigma_A} = \frac{\sigma_A}{\sigma_x}.$$

The correlation between the yields of any two farms, j and k, in the same area is:

$$r_{jk} = \frac{\Sigma_t x_{tj} x_{tk}}{\sqrt{\Sigma_t x_{tj}^2}\sqrt{\Sigma_t x_{tk}^2}} = \frac{\Sigma_t (A_t + v_{tj})(A_t + v_{tk})/T}{\sigma_j \sigma_k} = \frac{\Sigma_t (A_t^2 + A_t v_{tj} + A_t v_{tk} + v_{tj} v_{tk})/T}{\sigma_j \sigma_k}$$

So, taking expectations over j, it follows that $E(\Sigma_t A_t v_{tj}) = E(\Sigma_t A_t v_{tk}) = 0$ because:

$$\Sigma_j \Sigma_t A_t v_{tj}/J = \frac{\Sigma_t (A_t \Sigma_j v_{tj})}{J} = 0$$

Similarly,

$$E\left(\sum_t v_{tj} v_{tk}\right) = 0.$$

This follows because, taking expectations over j and k,

$$E\left(\sum_t v_{tj} v_{tk}\right) = \sum_j \sum_k \sum_t v_{tk} v_{tk}/JK = \sum_t \sum_k v_{tk} \sum_j \frac{v_{tj}}{JK} = 0.$$

Also $\sigma_j = \sigma_k = \sigma_x$, given that each farm is assumed to have the same variance. Hence:

$$r_{jk} = \frac{\sigma_A^2}{\sigma_x^2} = r_{Ax}^2$$

Next consider the correlations between yields at different levels of geographic aggregation. Let:

    x = farm yield

    c = county yield

    s = state yield

    w = major western US yield.

Then,

$$r_{cx} = \frac{\sigma_c}{\sigma_x}, \ r_{sc} = \frac{\sigma_s}{\sigma_c}, \ r_{sx} = \frac{\sigma_s}{\sigma_x} = \frac{\sigma_s}{\sigma_c} \frac{\sigma_c}{\sigma_x} = r_{cx} r_{sc}$$

$$r_{wx} = \frac{\sigma_w}{\sigma_x} = \frac{\sigma_w}{\sigma_s} \frac{\sigma_s}{\sigma_c} \frac{\sigma_c}{\sigma_x} = r_{ws} r_{sc} r_{cx}$$

       Standard deviations at the various levels of geographic aggregation can be approximated from various sources for the United States. Estimates of σ_x (farm yield standard deviations) can be obtained from from USDA Risk Management Agency farm yield files, from RMA yield rates, or from aggregate premium, liability and average coverage levels.Estimates of σ_c (county yield standard deviations) can be obtained from RMA GRP rates; estimates of σ_s (state yield standard deviations) can be obtained from state level USDA National Agricultural Statistical Service (NASS) time series data (appropriately detrended); and estimates of σ_w western region yield standard deviations) can be obtained from major NASS western wheat producing state aggregate yield data (appropriately detrended). Average areas for counties, states, and the western region could then be calculated and correlations between farm yields and yields for areas of different sizes could be estimated as a function of area.

Finally, note that the correlation between precipitation at a weather station and yield at farm k, which is not located at the station is simply $r_{pk} = r_{pj}r_{jk}$, where j identifies the farm at the weather station site and r_{pj} is the correlation between precipitation at the weather station and yield at the farm on which the weather station is located.