Designed for Development Impact: Next Generation Approaches to Index Insurance for Smallholder Farmers[1]

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Decades of research and observation have demonstrated that risk is economically costly in low-income agricultural economies, prompting protective self-insurance strategies that keep small farmers poor as they eschew remunerative, but risky opportunities. Making matters worse, self and community-based insurance strategies are at best only partially effective, leaving small farm households to costly ex post coping mechanisms that compromise the human capital of the next generation.[2] These problems are further compounded because risk itself stunts the development of rural financial markets, making it that much harder for small farmers to capitalize and move forward with new technologies and market opportunities.

While the costs of risk have long been recognized, recent technological advances in remote sensing and automated weather measurement have opened the door to innovative index insurance contracts that can transfer the correlated or covariant risk out of small farm economic systems. However, realizing the risk transfer potential of these advances (as well as the potential of older ideas like area yield insurance) faces both demand and supply constraints. Fortunately, a number of recent projects have shown that the supply side challenges can be overcome. Index contracts based on area yields, weather and remotely sensed vegetative growth data have all been designed and approved by regulatory bodies, offered for sale by commercial providers and reinsured by international reinsurance companies.

Despite this supply side progress, uptake of contracts in many of these pilots has at times been tepid, and there is little evidence to date that index contracts have solved the development problems that make risk costly to small farm households. In a review of recent experience with weather index insurance, IFAD and WFP (2010) observe that in order to be sustainable, insurance contracts must resolve these demand side constraints by finding ways to minimize the uninsured 'basis risk' not covered by index contracts, and to link farmers with productivity-enhancing services.

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[1] This paper draws on collaborative work with Rachid Laajaj, Lan Cheng and Alexander Sarris. These three individuals deserve much of the credit, but none of the blame for what follows.
[2] For a particularly disturbing example of the long-run costs of autarchic coping strategies, see Hoddinott (2006) and Hodinott and Kinsey (2001).

This paper fleshes out these observations and proposes that the next generation of index insurance contracts be designed for development impact by:

1. *Intelligently designing contracts to reduce basis risk*
   Success in this realm will in important instances require moving beyond weather-based contracts and using either area yield indices, vegetation indices based on satellite images or hybrid combinations of these information sources. Choosing between these information sources and designing optimal, basis risk reducing contracts will further require a demand-based approach, rooted in data on actual farmer outcomes and livelihood strategies.

2. *Systematically interlinking insurance with rural financial intermediaries*
   Risk is a development problem precisely because it forces small-scale farmers into self-insurance strategies that leave remunerative but risky economic opportunities unexploited. By explicitly linking index insurance with the finance needed to take up these new opportunities, index contracts can overcome the constraints to insurance uptake created by basis risk and contract loadings that make insurance expensive. Exactly how this interlinkage can be done depends critically on the nature of the existing property rights regime and financial market environment.

The next section introduces basic concepts of agricultural risk and of index insurance, illustrating both the strengths and the weaknesses of index insurance from the perspective of the small farm household. Section 2 then shows how micro household data can be used to intelligently design contracts through choice of signal and through choice of a statistically optimal loss and indemnity functions. Section 3 then shows how credit-insurance interlinkage can be used to overcome problems of uninsured basis risk and contract loadings in order to create a demand-worthy index insurance contract designed for development impact. Section 4 concludes.

Section 1 Index Insurance Basics

This section introduces a basic approach to thinking about the index insurance problem from the perspective of the small farm household. After introducing some basic notation that allows us to decompose the risk faced by small farm households under index insurance contracts, this section considers the potential effectiveness (and costs) of index insurance relative to traditional mechanisms of self-insurance. These observations in turn open the door to consideration of the options for improving the relative desirability of index insurance and its development impacts.

1.1 Decomposing the Risks Faced by Agricultural Households[3]

The challenges of index insurance design are best understood by rooting the discussion in the household level outcomes that are ultimately what matter from a development impact perspective. Random or uncontrollable forces that cause real, consumable household income to dip below its typical or average value are of particular concern to households. The goal of insurance is to protect households against such deviations. For a typical household *h* that resides in geographic zone *z,* we can in principal measure the deviation it faces in year *t* as:

$$y^*_{hzt} = y_{hzt} - \mu_{hz},$$

where y^*_{hzt} measure the crop yields that in part determine real household income and μ_{hz} are long-term average yields for that household.[4]

For reasons that are well described in the literature, agricultural index insurance works not by insuring the household directly against its own deviations,[5] but instead by insuring a direct or predicted measure of the average or typical yield deviation experienced by neighboring households in region *z.* Using parallel notation to that used for the household, we can write this average deviation in the zone as:

$$\bar{y}^*_{zt} = \bar{y}_{zt} - \mu_z,$$

where $\bar{y}_{zt}$ is average yields in the zone in year *t* and μ_z is the long-term zone average yield.

The key question facing index insurance is how closely do household yield variations (y^*_{hzt}) track or follow zone deviations ($\bar{y}^*_{zt}$). If the individual household's yields were exactly 100 kilos below the household's long-term average every time zone yields were 100 kilos below the zone's long-term average (i.e., if $y^*_{hzt} = \bar{y}^*_{zt}$), then index insurance would perfectly cover all risks faced by the household. The problem of course is that no index will perfectly correlate with any individual's losses.

[3] Appendix A below gives more thoroughly discusses the decomposition of the risk faced by households.
[4] Note that *y* could also be crop revenue (in which case the insurance would also offer price insurance) or some mix of other income components.
[5] A myriad of experience shows, trying to insure all sources of variation in agricultural outcomes for small farmers is beset by a host of problems rooted in the costs of obtaining information on small farm outcomes that renders such insurance infeasible (see Hazell, 1992).

There are three reasons that the individual household's y^*_{hzt} may not perfectly track deviations in the zone, $\bar{y}^*_{zt}$:

1. *Pure Idiosyncratic Risk*
   A single farm's crop may suffer damage from idiosyncratic factor such as animal or bird damage, or highly localized weather events. Different agro-ecological zones are characterized by different levels of pure idiosyncratic risk.[6]

2. *Noise Created by the Scale of the Geographic Zone Covered by a Single Index*
   As the geographic zone covered by a single index increases in size, household deviations will track less well with deviations in the index. For example, an weather-based index that only has to cover households within 1 kilometer of the weather station will track household outcomes better than an index that has to cover all households within 30 kilometers for the weather station.

3. *Noise Created by Index Prediction Errors*
   The average outcome in a zone can be measured directly with high precision (as with area yield contracts in the US where $\bar{y}_{zt}$ is measured directly with a tolerance of +/- 2%), or it can be predicted based with weather or satellite information that is likely to be cheaper to implement, but also likely to have a larger margin of error.

Together these three elements that create what is called basis risk, deviations in yield experienced by the household that are not correlated by deviations in the index and that are therefore uninsured by the index insurance contract. Because the second two sources of basis risk are influenced by design of the contract (geographic scope and exact index used), we will refer to them together as "design effects" on basis risk.

[6] In the Sahel, for example, rainfall can be highly localized, creating significant variations in yield deviations form one village to the next.

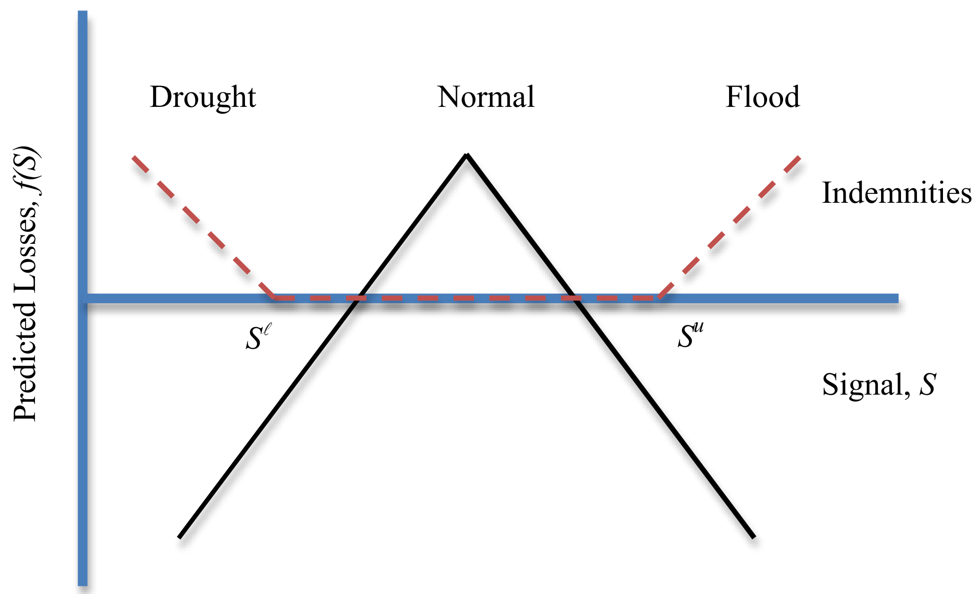

Figure 1 A Stylized Rainfall Index Insurance Contract

1.2 Index Insurance Contracts when the Opportunity Set is Fixed

In this section, we will consider index insurance contracts when they are not interlinked with new economic opportunities. That is, we will assume that the farm household grows the same crops with the same technology with or without index insurance. In Section 2 below, we will argue that unless index insurance is interlinked with expanded economic opportunities, demand for the insurance will likely be low. Correspondingly, demand or uptake of new opportunities is also likely to be low for small farm sectors unless it is interlinked with index insurance.

Building on the discussion in the prior section, we can now define an index insurance contract as an indemnity schedule that links predicted losses based on the contractually designated signal to the financial payoffs made to the insured party. Figure 1 illustrates the indemnity schedule that might accompany a zone-level yield loss predictor function built around a rainfall signal.[7] The contract is defined by a lower and upper strike levels, S^ℓ and S^u. When the measured rainfall dips below S^ℓ (signaling drought), indemnity payouts begin as shown by the dashed line in Figure 1. Similarly, when rainfall exceeds the upper strike

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[7] Contracts with exactly this structure have been used in a number of important index insurance pilots, including ones in Ethiopia, Malawi, Kenya and India.

point (signaling flood conditions), payouts again begin to the insured party. Implicit in this kind of contract is that yield deviations (losses) at the zone level are linear in rainfall as shown by the solid line if Figure 1. Such linearity seems unlikely to accurately predict farmer losses, implying that an index contract with the form shown in Figure 1 is likely have large design effects that reduce the effectiveness of the contract. Section 2 will discuss in detail statistically optimal predictor functions. Suffice it to say here, that the stylized linearity represented in Figure 1 is highly unlikely to be the design that minimizes design effects.

Using information on the probability distribution of the signal, the index insurance contract can be priced, with actuarially fair premium defined as the expected or long-term average payout under the indemnity schedule. The market premium is then defined as the actuarially fair premium plus mark-ups or loadings associated with the costs of providing the contract (sales costs, capital costs, reinsurance costs, etc.).

A number of existing pilot projects have shown that index insurance contracts of this form can be defined and supplied by the commercial market [add citations]. While these supply side achievements are absolutely critical, index insurance will only have its desired development impacts if it meets with both supply and (informed) demand. To illustrate the demand side challenges, we consider a stylized small farm household that obtains 50% of its income from non-agricultural sources and 50% of its income (on average) from farm production using a relatively safe, low input technology. Details on these assumptions are given in Appendix B at the end of the paper.

Figure 2 illustrates the risk faced by this stylized farming household both with and without index insurance. The horizontal axis displays the income available for family consumption as a percentage of the family's average consumption without insurance (100% would thus be the family's average consumption level). The vertical axis shows the cumulative probability of different consumption outcomes for the family. The red, small-dash line shows these probabilities when the family does not have an index insurance contract. 50% of the time, the family will have consumption levels at or below its average, and under the assumptions made for the simulation, 10% of the time, the family will need to make do with consumption at or below 75% of its normal level.

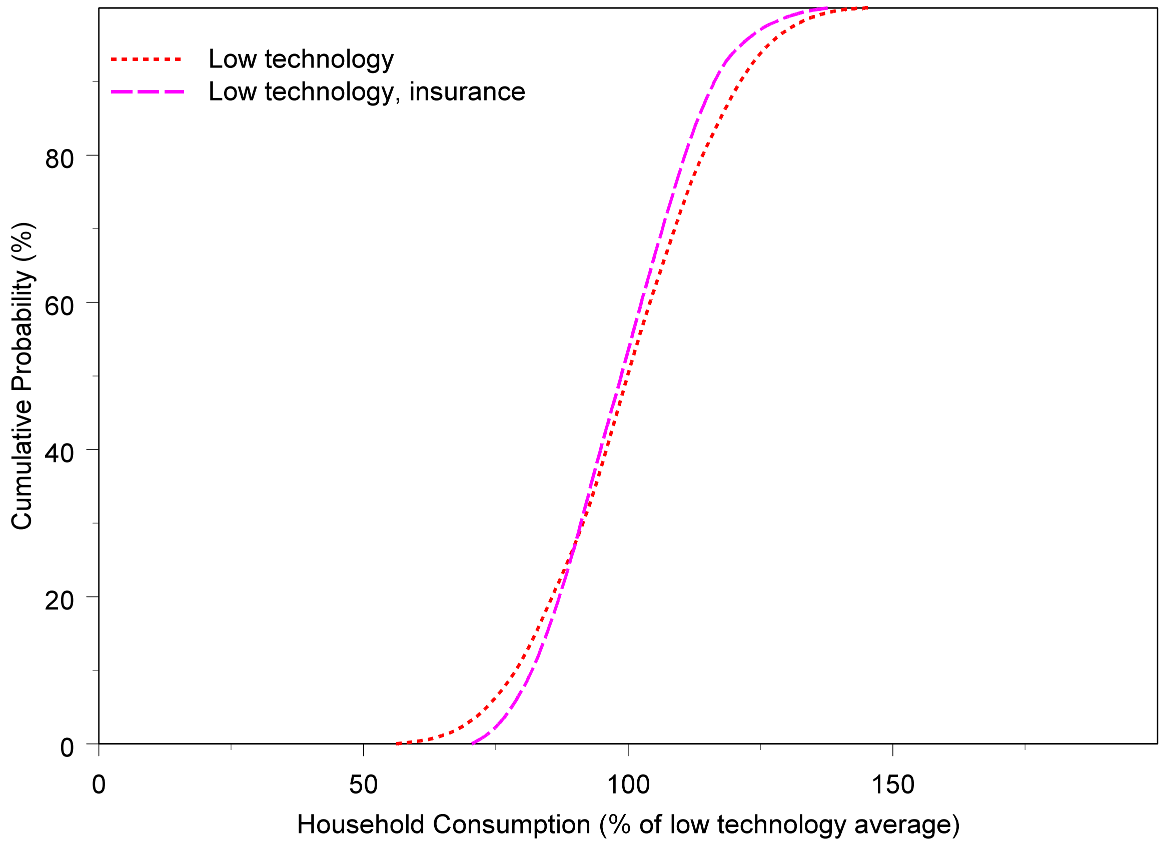

Figure 2 Insuring the Traditional Technology

The magenta large-dash line shows the consumption probabilities in the case that the family's agricultural production is insured by an index contract. For illustrative purposes, we have assumed that half of the yield variation faced by the family is covered by the index contract and that the other half is uncovered basis risk. We also assume that premium charged for the contract has a loading of 20%, meaning that the household pays 20% more in premia than it expects to recover from indemnity payments.[8] Finally, we assume that the strike points are set such that payoffs begin anytime measured or predicted zone yields fall below their average level.

Careful examination of Figure 2 shows both the strengths and weaknesses of index insurance. First, the probabilities of extremely low outcomes drops substantially. With insurance, there is only a 2% chance that household consumption will fall below 75% of its normal level (down from a 10% chance without insurance). While lower, this probability is not zero, reflecting the fact that the contract does not cover all risks. Complete insurance coverage without

[8] This loading level is seen to be typical for agricultural index insurance contracts offered by the US Department of Agriculture (see Smith and Watts, 2009).

basis risk would stabilize household consumption at its mean level (less markup or loading costs). As can be seen from Figure 2, substantial basis risk remains relative to this idealized (but infeasible) complete insurance.

This factor, along with the fact that premiums are marked up by 20% means that even with insurance, the family consumption can still fall below its pre-insurance average of 100%. Household average income is also reduced by a percent or two because of the loadings charged to the insurance. While a case can be made to at least partially subsidize insurance premia for small-scale farmers, these distribution functions make clear that when conceived this way, index insurance presents the household a zero sum game: the (imperfect) reduction in the probability of low outcomes is purchased at the cost of reduced average income.

1.3 The Demand Problematic for Index Insurance and Possible Solutions

The crossing cumulative probability curves in Figure 2 captures the tradeoff inherent in index insurance when the insurance is not interlinked with an expanded set of opportunities. The fact that the probability curve with insurance lies below the uninsured curve for low outcomes is a good thing, showing that such disastrous outcomes are less likely with insurance. However, the fact that uninsured probability curve lies below the insured curve at higher levels of consumptions reflects the costliness of the insurance. In conventional economic parlance, only those individuals who are highly risk averse (*i.e.*, deeply worried about low outcomes) will purchase the insurance in the face of this tradeoff.

It is important to stress that these simulation results capture the stylized fact that small-scale agricultural households are already partially insured by having non-agricultural income sources and by choosing crops and technologies that use few inputs and thereby reduce the risk exposure of the household.

As summarized by the recent IFAD/WFP (2010) study of weather index insurance, many pilot projects have met with weak demand. While there are a plethora of reasons that might explain sluggish uptake of novel index contracts (including lack of understanding and trust in the contract), the fact that self-insurance, basis risk and loadings compromise the desirability of the contract is surely also part of the explanation. Recognizing this problem, the IFAD/WFP report suggests two things: First, it advocates better-designed contracts that have lower basis risk. Second, it advocates combining index insurance with other agricultural services, creating what it calls a value added proposition.

The remaining two sections of this paper are dedicated to building on these observations, expanding and combining them into a second-generation approach to index insurance for small-scale farmers.

Section 2 Designing Contracts to Minimize Basis Risk

Figure 1 above used a standard rainfall contract to illustrate the more general functioning of index insurance. While index insurance is sometimes generically called weather or rainfall insurance, the importance of the basis risk problem just discussed demands that well-designed contracts consider the range of options available and choose an optimal, basis risk-minimizing, contract design.

While rainfall contracts like that illustrated in Figure 1 are typically based on some expert advice on rainfall levels at which crop damage occurs, the *ad hoc* linear loss and indemnity functions used in some contracts are unlikely to be statistically optimal predictors that minimize the prediction error. Fortunately, widely available micro data on farm households allows estimation of an optimal predicted loss function for rainfall or any other candidate signal.[9] The resulting contracts, or hybrid combinations of them, can then be compared to see which one offers the best value to the beneficiary population, taking into account the predictive power of the signal as well as the cost of obtaining it.

To illustrate these ideas and their implementation, this section will summarize an analysis of West African grain crops that examined rainfall, area yield and satellite-based index insurance contracts.

2.1 Minimizing Basis Risk for West African Grain Farmers

To illustrate contract design principals, we consider grain yields in 6 villages in Burkina Faso where the International Crop Research Institute for the Semi-arid tropics (ICRISAT) intensively interviewed farm households over the 1980 to 1985 period. Detailed production data were conducted from 25 households in each village for the three cropping years 1980/81-1982-83 (see Carter, 1997, for details on the data). For the analysis here, we aggregated each household's production across all of its sorghum and millet fields to create an annual grain yield figure, y_{hzt}, for each household. Using this data, we can easily calculate $\bar{\mu}_{hz}$ as the average yield for each household over the three years of survey data.

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[9] The remote sensing literature has already made substantial progress in identifying transformations of satellite signals of vegetative cover that best predict farmer yield outcomes on the ground. The same methodology can also be applied to other potential insurance indices.

The goal of a basis risk minimizing contract is thus to create an index that explains as much of the variation in $y^*_{hzt} = [y_{hzt} - \mu_{hz}]$ as possible.

One possible index would be a measure of average village yields. A contact based on this village yield index would pay off to farmers based on the degree to which village yields deviate from the long-term average. We can replicate an area yield index simply by taking the average yield across all households in each village for each crop year. Within a village, all farmers' fields are at most a few kilometers apart. While the Sahelian region from which these data come is famous for large idiosyncratic risk generated by highly variable local weather patterns, we would still anticipate that each household's yields would closely follow its village average yields. In this case, a contract based on village average yields would be relatively effective as insurance indemnity payments would tend to correctly compensate households for losses experienced.

The analysis detailed in Laajaj and Carter (2009) shows that no less than one third of the total fluctuations experienced by households can be explained by average village grain yields. The other two-thirds or less represent the basis risk that would be uninsured with this contract. While it is surprising that as little as one third of the risk may be common across villagers, note that it is precisely this correlated risk that households would have trouble managing it through traditional mechanisms of social sharing and reciprocity.
While this village level area yield index represents the basis risk minimizing index insurance contract for this semi-arid environment of West Africa,[10] it would in all likelihood be impractically expensive to implement as it would require an annual yield survey in each village where households were covered. We therefore turn to see if there are alternative cheaper mechanisms that can yield similar predictive power to the area yield index.

The ICRISAT data includes rainfall information collected at the level of each village. Note that this rainfall information is extremely high density as it is the equivalent of having a weather station every few kilometers. In practice, such a high density of weather stations is not economically feasible. None the less, it gives us another useful benchmark against which to compare the performance of a third possible index, one based on satellite data on vegetative cover (NDVI). Because this latter kind of data is less familiar, we present a brief overview of it before comparing the performance of NDVI-based contracts with that of alternative contracts based on more familiar measures.

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[10] Strictly speaking, the 25 households surveyed by ICRISAT is probably too small a number for a proper yield survey. A larger survey would provide a better estimate of village yields and a better insurance contract.

2.2 The Normalized Difference Vegetation Index

The Normalized Difference Vegetation Index (NDVI) is a satellite-based measure of vegetation density. NDVI is scaled to lie between zero and one, with low values signaling very little vegetative growth and high values showing dense vegetation. Every ten days NDVI is measured at a resolution of 8 km by 8 km (that is, a unique NDVI measure is provided for each 8 km by 8 km grid). NDVI measures at this resolution are freely available on the FEWS NET (Family Early Warning System Network) website.[11] The availability of NDVI at this resolution is equivalent to having a separate weather station (or an area yield survey) for each 8 km square. If NDVI can be shown to have similar capacity to predict individual farmer yields as meteorological or area yield data, then clearly it would emerge as the preferred basis for an insurance index on simple cost and simplicity grounds. In addition, NDVI is available going back to 1981, meaning that the long-term data needed to accurately price an insurance index are available.

Figure 1 illustrates how NDVI works. The diagrams on the left side of the figure display actual NDVI data for West Africa. A brown to green color spectrum has been used to graphically display the zero to one NDVI scale, with browner colors signaling low NDVI values and greener colors high NDVI values. The insert in each diagram shows the individual 8 km square pixels for the region surrounding the village of Silgey, one of the six villages included in the ICRISAT study in Burkina Faso. The dot on the insert is the pixel where the village center is located.

The first of the three charts on the right side of Figure 1 show 1981-1983 grain yields from Silgey as measured by the ICRIST Village Level Studies discussed more below. The middle chart displays average NDVI for that time period, while the bottom chart shows rainfall as measured by a village rainfall gauge maintained by the ICRISAT study. Impressionistically, these figures show that NDVI tracks village level yields. While this is encouraging, we need to more carefully evaluate the precision with which NDVI can predict village yields and form the basis for a valuable insurance index contract.

[11] Higher resolution data (that measure NDVI for each 30 meters by 30 meter square) are available for purchase.

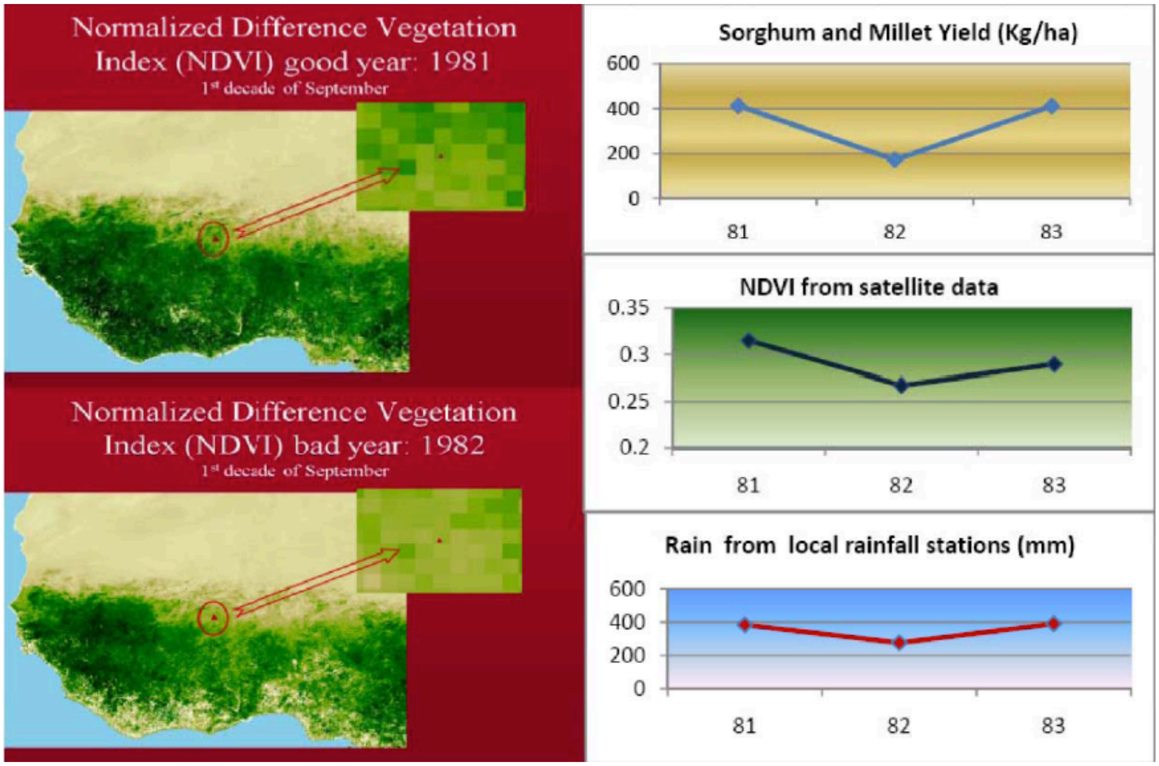

Figure 3 Yield Prediction using Satellite Data

2.3 Area Yield, Weather and NDVI Contracts Compared

While the raw NDVI signal could be used as the basis for an index insurance contract, there is a well developed literature on remote sensing that has explored the transformations of NDVI that best predict crop yields. For the analysis here, we emply the transformation of NDVI information called the Vegetation Condition Index (VCI). Suggested by Kogan (1991), an expert in early drought detection and watch from NOAA, VCI is defined as:

$$VCI = 100*(NDVI - NDVI_{min})/(NDVI_{max} - NDVI_{min})$$

For a given village, the VCI uses long term series of NDVI to relate present NDVI to the extremes values observed since 1982 at this same time of the year.

Figure 4 graphs the VCI measure for the 1983 for village of Kolbila, another of the ICRISAT study sites. Also shown on the graph are the historical minimum and maximum values of NDVI for Kolbila. As can be seen in Figure 2, the VCI for Kolibila was close to zero in April, 1983, but around one half in September of that same year. An advantage of the VCI transformation is that it facilitates the use of NDVI data coming from heterogeneous places.

So how much basis risk would exist under an index insurance contract written on the village specific VCI? Carter and Laajaj estimate the statistically optimal (basis risk-minimizing) predictor function that can be obtained for the VCI.

They carry out a similar exercise using the village level rainfall data. They find that the VCI index achieves 89% of the variance reduction of the village yield index. The rainfall measure achieves only 75% of the reduction. Interestingly, when the VCI and rainfall measures are combined into a hybrid index, no additional variance reduction is achieved beyond that obtainable with the VCI-based index alone.

These findings should not be generalized to other agro-ecological environments.

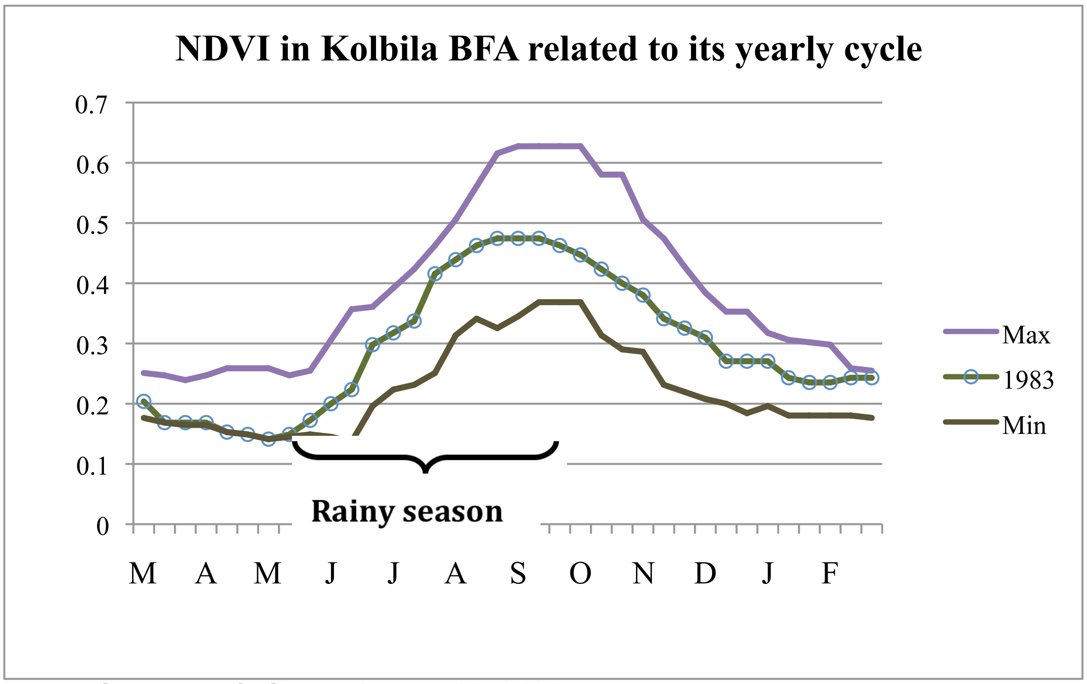

Figure 4 Calculation of VCI using Max and Min NDVI

They do however show that designing a cost-effective index insurance contract that minimizes basis risk should consider a variety of index options. At the same time, the analysis also shows that there are limits to the elimination of basis risk, even through optimal contract design. The next section explores the possibility for further improving the development impact value and sustainability of insurance by interlinking it with credit in ways that are sensitive to the underlying nature of the collateral environment.

Section 3 Interlinking Insurance and Credit

The analysis in Section 1 assumed that the small-scale farm household had access to only one ("traditional") economic activity. While the risks associated with such activities are surely important, development economics has long been preoccupied with the notion that one of the biggest costs of risk is that it induces farm households to 'income smooth," by shying away from new technologies and economic opportunities that offer improved incomes on average, but substantially increase the risk of low outcomes.[12] In addition, risk stunts the development of rural financial markets, compounding the adoption problems for liquidity-constrained farm households. This section will argue that explicitly connecting index insurance with these kinds of activities will not only solve the development problem that makes risk so costly, but will also resolve the problem of tepid insurance demand detailed above.

3.1 High Returning Economic Activities and Small-scale Farm Households

High returning economic activities typically require significant up-front investment in purchased inputs of improved seeds, fertilizers and other agro-chemicals. This factor alone increases the risk exposure of the family as a drought year means negative, not just zero net income. In addition, the yield variance of high returning activities also tends to be higher, in part because these activities are less well-adapted to climatic stress than are traditional activities that have evolved in the farm's specific agro-ecological system. Finally, the increased cash costs of production may simply exceed the liquidity available to the household, making access to capital (through financial intermediaries or value chain operators) indispensable.

Figure 5 illustrates the cumulative distribution function for a stylized high returning activity. Compared to the traditional activity (shown here, as in Figure 2 as the red small-dash line), the high returning activity has mean returns that are 25% higher than the traditional agricultural activity. It also realistically requires purchased inputs that equal the total annual non-farm income of the household. Under these assumptions, the solid black line shows the probability of different household consumption outcomes under the high returning activity when the cash costs are either completely self-financed by the household, or, equivalently, financed by a fully collateralized loan contract.

As can be seen, under the high technology the household faces almost a 10% chance that its total consumption will be less than 50% of the average income it can obtain under the low technology. However, some 40% of the time household consumption will be at least 25% higher than average income under the low technology. This very stark tradeoff is the one from which many small-scale farming households shy away.[13]

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[12] For specific empirical examples, see Barham *et al*. (1995), Herdt and Wickham (1978) and the review paper by Feder, Just and Zilberman (1995).
[13] When analyzed from the conventional economic perspective of expected utility theory, only households with very low degrees of risk aversion would adopt the technology (see Carter *et al.*,

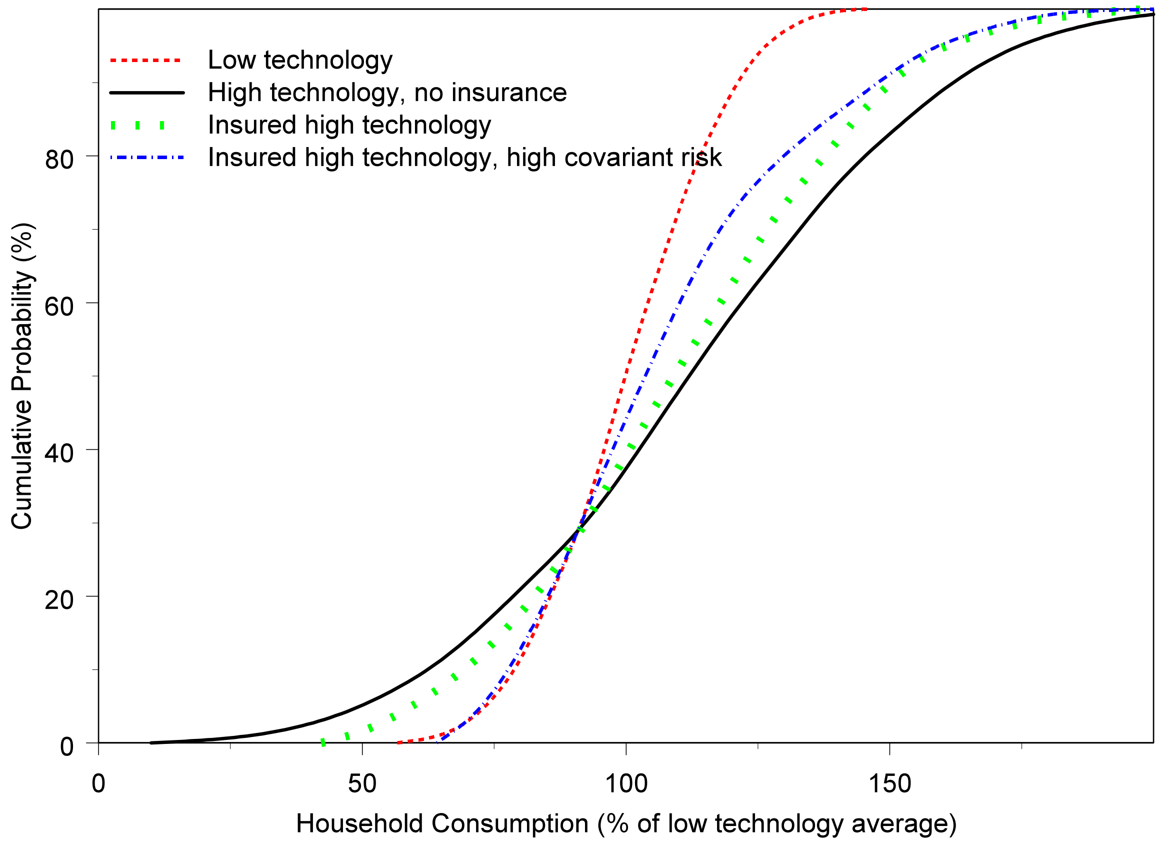

Figure 5 Interlinking Insurance and Credit for Technology Uptake

The decision to utilize the traditional technology when the high returning activity is available and financially feasible can be examined as an insurance-like decision. From this perspective, self-insurance through adoption of the traditional technology carries a very high loading as it reduces expected household income from agriculture by 25% and reduces overall household consumption by 12.5%. This self-insurance strategy also carries uninsured or basis risk, as the self-insured household continues to face positive probabilities of low consumption outcomes. When seen from a development perspective whose goal is to improve household economic wellbeing, the challenge of index insurance is not to eliminate all basis risk and loadings, but simply to do better than the costly self-insurance that is available by relying solely on traditional technologies. As the next sections will describe, the mechanisms for doing this will depend critically on the nature of the financial market.

2010). From a safety first perspective (*e.g.*, see Roumasett 1976), no agent would be expected to adopt the high technology.

3.2 Index Insurance and Adoption of the High Return Activity when Loan Contracts Are Fully Collateralized

In the discussion in this and the following section, we assume that loans are offered by a competitive lending sector in which loans are offered on terms that yield lenders expected profits exactly equal to the economy-wide opportunity cost of capital. It is also assumed that borrowers repay loans to the extent possible using all realized agricultural income and any contractually required collateral. When loans are fully collateralized—meaning that the collateral is sufficient to fully repay the loan even when there is a crop failure—the lender bears no risk. Under these terms, a loan contract functions much like self-finance as the farm household is fully liable and carries the full risk associated with adopting the high return activity. Economies where land is individually titled may allow for complete loan collateralization. The next section will discuss the case of incomplete loan collateralization.

Because the fully collateralized loan contract functions like self-finance, only the least risk averse households would be willing to accept the probability of very low outcomes in return for the prospect of higher incomes, as discussed above. This case, in which small-scale farm households have access to a loan contract to finance a high returning activity, but turn it decline to take the contract and adopt the activity, corresponds to what Boucher et al. (2008) describe as risk rationing. These authors show theoretically that risk rationing is most likely to happen with lower wealth households and that empirically, important numbers of small farmers in Central and South America are risk rationed.[14]

Under a fully collateralized loan contract, the benefits of index insurance will accrue directly to the household, which carries all risk. The green dotted line in Figure 5 shows the impact of index insurance interlinked with credit and technology uptake. This interlinked insurance arrangement almost eliminates the risk of consumption falling below 50% of the low technology average. At the same time, probabilities of outcomes between 50% and 80% of that average are still higher under the interlinked insurance than under the self-insurance, low technology strategy. Beyond that level, the interlinked contract strongly dominates the self-insurance strategy as almost 70% of the time it offers higher household consumption than would the self-insurance strategy. While this interlinked contract still presents the household with a tradeoff (higher returns at some increased risk of low outcomes), the tradeoff is much less severe than that offered by the high technology without insurance. Analysis by Carter *et al.* (2010) shows that while this interlinked contract is still characterized by a

[14] Work reported in Boucher et al. (2008) suggests that as many as 20% of small farmers in Latin America may be risk rationed.

tradeoff, all but the most risk averse agents would prefer the interlinked contract to low technology, self insurance strategy.

The tradeoff that remains even with the interlinked contract can be reduced or even eliminated completely if basis risk can be reduced under the index insurance contract. The green dotted line in Figure 5 is constructed based on the assumption that index insurance can cover half the risk faced by the farm household and that the other half remains as basis risk. This is roughly the quality of the insurance that can be obtained using satellite signals for Sahelian grain producers. However, in environments where more of the risk is covariant risk, or where intelligent contract design can further reduce design effects on basis risk, it is possible for interlinked contracts to completely dominate self-insurance strategies.

The blue dot-dash line in Figure 5 shows the cumulative distribution of family consumption when two thirds of the risk can be covered by an index contract and one third is uninsured basis risk. As can be seen from Figure 5, under these values the index contract unambiguously dominates the self-insurance strategy. The downside risk is identical under the interlinked contract and it offers substantial prospects for consumption outcomes that are much higher than those obtainable under self-insurance. Even the most risk averse agent would be expected to prefer the interlinked arrangement to the self-insurance of low technology.

It is important to note that there is still basis risk and loadings under this interlinked contract. While it is thus inferior to a perfect, full coverage insurance contract, such an infeasible option is not an especially interesting point of comparison. The more interesting comparison is with the extant self-insurance strategy with its degree of basis risk and high loadings. Interlinkage of credit with insurance is important precisely because it opens the door to dominating self-insurance and crowding in technological change.

The discussion so far on interlinkage has assumed that loans are fully collateralized so that the household bears all the direct risk of a production shortfall that leads to default. Before turning to consider how interlinkage might work in environments with low collateral, it is important to consider how risk can undermine credit supply even in high collateral environments.

While lenders do not directly bear any immediate risk under full collateralization, they do potentially face what might be termed political economy risk. In the case of a major covariant shock that leads to crop failure and exposed small farm household to collateral forfeiture, lenders might well anticipate political pressure to forgive outstanding debt rather than reposes farmland. As described by Tarazona and Trivelli (2005), this scenario took place following the 1998 El Nino event in Peru. Note that this political economy risk is directly tied to covariant shocks as it is the fact that large numbers of farmers can point to an easily observable event that creates the political possibility for this kind of debt forgiveness.

The magnitude of this political economy risk depends on the lender's loan portfolio. As modeled by Carter et al. (2010), lenders will react at the market level by increasing the rate of return required of (uninsured) agricultural loans as the fraction of the loan portfolio in agriculture increases. An increase in the number of small farms taking up loans (induced, say, by the availability of index insurance contracts) would thus be expected to provoke an increase in the cost of capital to the agricultural sector, a force that would tend to choke off the increased uptake.

Explicitly interlinking loan with index insurance contracts would be expected to resolve this problem. While index insurance contracts do not cover all risks, they do cover the covariant risks that power the political economy problem faced by lenders. The next section will discuss interlinkage more thoroughly in the context of low collateral environments where interlinkage is potentially of even greater importance.

3.3 Index Insurance and Adoption of the High Return Activity in Low Collateral Environments

Full collateralization of loan contracts is unlikely, especially in many smallholder areas in sub-Saharan Africa. When loans are undercollateralized, some of the risk of low yield levels is carried by the lender. Assuming lenders are even willing to issue low collateral loans, they will need charge higher contractual interest rates in to achieve a given expected rate of return. In addition, because default on agricultural loans are likely to be correlated, lenders are likely to severely limit the amount of agricultural loans in their portfolio (Tarazano and Trivelli, 2005) or to demand an ever higher expected rate of return on agricultural loans in order to compensate for this additional balance sheet risk when they increase the amount of agricultural loans in their portfolio (Carter, Cheng and Sarris, 2010).

In this low collateral environment, the offer of index insurance contracts to farm households will meet with less demand than in high collateral environment as much of the benefit of the insurance will accrue to the lender who bears a substantial part of the risk in the low collateral environment. In this context, supply of credit to finance new technologies is likely to be restricted and expensive, and there is also likely to be no independent demand for insurance on the part of farm households.

Interlinked insurance-credit contracts are one possible way out of this conundrum in low collateral environments. As analyzed in more detail by Carter, Cheng and

Sarris, an index insurance contract that covers the covariant risk faced by lenders should be sufficient to relax the constraints that restrict the supply of credit to the small farm sector. At the same time, if lenders face competitive pressure, the loan rates will drop and reduce the cost of credit to the small farm household, creating yet more demand for capital and increased uptake of the high technology. While the mechanisms are somewhat different than the high collateral case considered in the section 3.2, the net result is almost identical in terms of the overall impact. As shown in Figure 5, index insurance contracts interlinked with credit and uptake of improved technology can dominate the high basis risk and implicit loadings that small farm households pay when they self-insure through adopting traditional technologies.

3.4 Marketing Interlinked Index Insurance

While compelling on its own terms, the interlinkage of intelligently designed index insurance contracts with credit also potentially offers important marketing advantages. In low collateral environments, in which most of the direct benefits of index insurance will accrue to lenders, it may make sense to market directly to lenders as portfolio insurance. While in a perfectly competitive loan markets the benefits of this portfolio insurance would trickle down to borrowers, in the real work in which rural loan markets are far from competitive a development impact oriented approach to insurance will need to consider contractual mechanism that insure that benefits of the insurance are indeed passed on to borrowers. In high collateral environments, interlinkage may still offer marketing advantages as a single contract can offer both credit and insurance.[15]

Section 4 Conclusion: Designed for Development Impact

Small farm agricultural insurance is not an end in itself. Its importance comes from its ability to impact a fundamental problem of economic development, namely the economically costly self-insurance and coping strategies that can make and keep smallholders poor. Approaching the insurance problem from this development impact perspective suggests a demand-centric approach to contract design, rooted in data on small farm households and their production technologies and constraints.

As explored in this paper, this approach allows evaluation of alternative insurance indices—area yield, satellite based, weather-based and hybrid combinations—and selection of a statistically optimal contract design that

[15] While true in the abstract, the ongoing Pisco, Peru cotton index insurance pilot illustrates the importance of making sure that interlinkage is properly set up so that loan officers enjoy the time and incentives to co-market credit and insurance.

reduces uninsured basis risk in a cost-effective fashion. In addition, this approach opens the way to context-sensitive interlinked credit-insurance contracts designed to simultaneously deepen financial markets and facilitate small farm technology uptake by operating on both the demand and supply sides of the agricultural credit market. As argued here, it is ultimately the combination of intelligently designed contracts with interlinkage that will allow index insurance to dominate small farm self-insurance strategies, sustain demand and, ultimately, achieve the desired development impact.

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