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

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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 insurance is only partially protect small farm households against the damaging drops in consumption that can irreversibly damage the long-term physical and cognitive development of young children. 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 these economic and human development costs of risk have long been recognized, recent technological advances in remote sensing and automated weather measurement open 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[2]) faces both demand- and supply-side constraints. 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, contract demand and uptake has been sometimes tepid, and there is little evidence to date that index contracts have helped small farmers better manage risk, achieving higher incomes for themselves and securing better human development for their children. 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. This paper fleshes out this observation and proposes

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[2] Area yield insurance measures average yields in a defined geographic area (e.g., a valley, or administrative district) and makes payments when these average yields fall below a specified 'strikepoint' level.

that the next generation of index insurance contracts be designed for demand and development impact through:

1. *Intelligent design of 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. *Systematic interlinkage of insurance with credit*
   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 of this paper 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 Agricultural Index Insurance Basics

This section introduces the index insurance problem from the perspective of the small farm household, considering 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 Index Insurance and the Risks Faced by Agricultural Households

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 reasons that are well described in the literature, agricultural index insurance works not by insuring the household directly against shortfalls in its own income or yields,[3] but instead by insuring a direct or predicted measure of the average or typical yield losses experienced by neighboring households in region. An index insurance contract can be represented as an indemnity schedule that links payments to an index that predict typical losses in the zone covered by the index. To avoid problems of moral hazard and adverse selection the index should not be able to be influenced by the insured, nor should its level depend on which particular individuals choose to purchase the insurance.

Figure 1 illustrates the indemnity schedule that might accompany a zone-level yield loss predictor function built around a rainfall signal. The horizontal axis shows a rainfall index (perhaps cumulative rainfall measured in millimeters) and the vertical axis shows indemnity payments. The contract is defined by a lower and an upper strike level, S^{ℓ} and S^{u} respectively. When the rainfall index 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 point (signaling flood conditions), payouts again begin to the insured farmers.

A key question facing index insurance is how closely do household yield shortfalls track the index of predicted shortfalls. If the index signaled exactly a 100 kilo loss every time the individual household's yields were 100 kilos below the household's long-term average, 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 in this way.

There are three reasons that the index that predicts average losses will not perfectly track individual household's yield shortfalls:

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[3] 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).

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 levels of pure idiosyncratic risk characterize different agro-ecological zones. In the Sahel, for example, rainfall is highly localized, creating significant variation in yield losses between neighboring villages, or even between households in the same village.

2. *Noise Created by the Geographic Scale of the Index*
   As the geographic zone covered by a single index increases in size, household losses will correlate less well with the insurance index. For example, a 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 of the weather station.

3. *Noise Created by Index Prediction Errors*
   The average loss within a defined geographic zone can be measured directly with high precision (as with area yield contracts in the US where yields are measured to a of +/- 2%), or it can be predicted using weather or satellite information that is likely to be cheaper to implement, but also likely to have a larger margin of error predicting even the average loss.

Together these three elements create what is called basis risk, yield losses experienced by the household that are not correlated with the insurance 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.

The linear contract structure in Figure 1 is simple, and close variants of it have been used in several important index insurance pilots, including ones in Ethiopia, Malawi, Kenya and India. However, implicit in this structure is the assumption that losses are linear in the rainfall index. Empirical analysis of the sensitivity of yields to rainfall like Carter's (1998) West Africa work suggests that yield losses respond in a non-linear way to rainfall shortages or excesses. If this is correct, then the common linear loss contracts will have large design effects that unnecessarily increase basis risk. Section 2 below will discuss in detail ways to estimate statistically optimal predictor functions that can be used to design more effective indices and contract. Suffice it to say here, that the stylized linear indemnity schedule represented in Figure 1 is highly unlikely to be the contract structure that minimizes design effects.

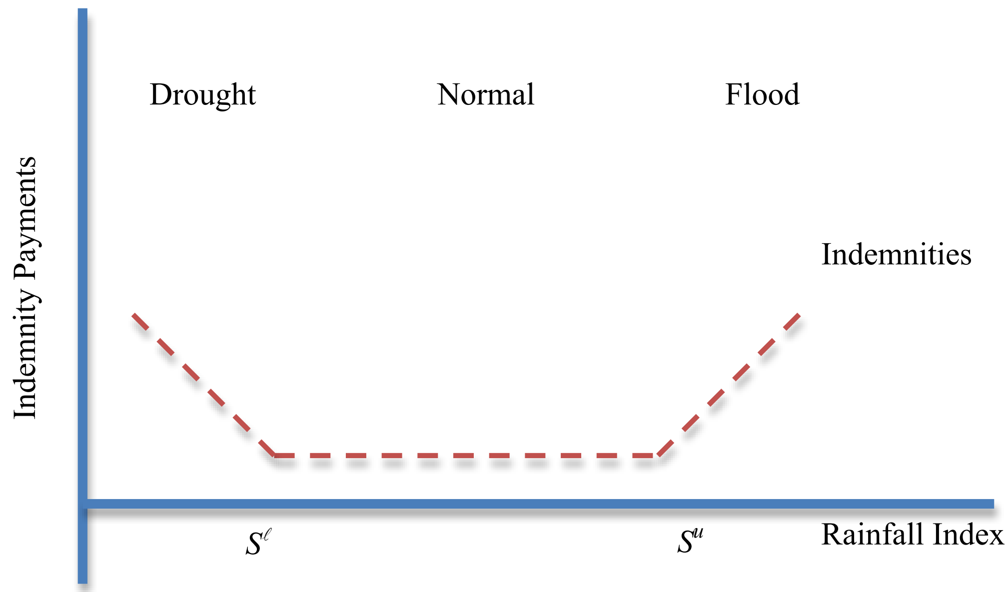

Figure 1 A Stylized Rainfall Index Insurance Contract

Once an indemnity schedule is designed, historical information on the index (*e.g.,* rainfall data) can be used to calculate the probability distribution of the index and the actuarially fair premium, which is simply the expected or long-term average payment 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.). Loading premia can vary based on the quality and quantity of the data used to construct the probability distribution of the signal. For agricultural index insurance contracts offered by the US Department of Agriculture the typical loading level is 20% (Smith and Watts, 2009).

A number of existing pilot projects have shown that index insurance contracts of this form can be defined and supplied by the commercial market. The IFAD/WFP (2010) study details many of these projects. In addition, recently introduced products that have also satisfied national and international insurance supply standards include a satellite-based livestock insurance contract in Kenya, and area yield contracts in Mali and Peru (details on these and other projects are available at http://i4.ucdavis.edu). While these supply side achievements are absolutely critical, index insurance will only have its desired development impacts if it also generates informed[4] demand and uptake.

1.2 Self-insurance versus Index Insurance Contracts without Interlinkage

As prelude to thinking about how to create index contracts that are demand-worthy, this section examines the demand for index insurance from the perspective of a typical small farm family that has a diversified livelihood strategy and has options for self-insuring against agricultural risk. In contrast to later analysis, this section will assume that insurance is not interlinked with credit or other opportunities to improve average family income. Specifically, we will assume that the farm household grows the same crops, with the same technology, with and without index insurance. In Section 2 below, we will argue that unless index insurance is in fact interlinked with expanded economic opportunities, demand for the insurance will likely be low. Correspondingly, demand or uptake of credit and new agricultural technologies is also likely to be low for small farm sectors unless it is interlinked with low-cost risk management tools, such as index insurance.

As detailed in the appendix at the end of this paper, we analyze demand for index insurance from the perspective of a 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 risky, but relatively safe, low input technology. For this analysis, we assume stylized levels of overall risk and a reasonable division of this risk between correlated risks (like weather and insect invasions) and idiosyncratic risks.

Under our assumptions, half of the time this family would have lower than average agricultural income and therefore lower than average household consumption. The other half of the time the family would have better than average consumption. Despite its self-insurance strategy, 10% of the time the family would face significantly reduced consumption (less than 75% of its average consumption level) due to a poor agricultural crop (see Appendix Figure A1). Put differently, the family faces 'basis' risk that is not insured under its self-insurance strategy. In addition, if the family eschews the adoption of more productive strategies (*e.g.*, greater levels of fertilization of its crop) in order to reduce risk, then it is also paying an implicit loading, meaning that self-insurance reduces its average income relative to what it could be. The challenge is

[4] Insurance will only have its development impacts if the insured understand its working and choose to modify their behavior (e.g., choice of production technology) accordingly.

whether index insurance—with its level of basis risk and loading—can do better than the family's stylized self-insurance strategy.

Index insurance gives the family the option to add a new risk management tool to its traditional risk management strategies. The analysis detailed in the appendix assumes that one half of all agricultural risk faced by the household is a correlated risk that can be covered by the index insurance contract. The other one half is basis risk (resulting from either true idiosyncratic risk or from design effects) that is not insured by the index insurance contract. The simulation analysis assumes that the family faces loading costs of 20%, meaning that after purchasing insurance, average family consumption will fall slightly below its pre-index insurance average.

As shown in the appendix, under these somewhat conservative assumptions, index insurance lowers the probability of extremely low consumption from about 10% to 3%. While lower, this probability is not zero, reflecting the reality of basis risk and the possibility that the family could have a low outcome and still not receive any compensating insurance payment under the index contract. In addition, because of loading costs, the contract presents the household with a zero sum game: the (imperfect) reduction in the probability of low consumption is purchased at the cost of reduced average income. As analyzed in greater detail by Carter et al. (2010), only the most risk-averse fraction of the population (those who are most deeply worried about low consumption outcomes) would find this kind of index insurance attractive. When combined with the other factors that might inhibit the adoption of a new, relatively complex contract (such as lack of understanding or trust that the insurance will really pay off as advertised), this tradeoff may explain the sometimes weak demand for index insurance when it is not combined with measures to simultaneously improve access to credit, improved technologies and new markets.

1.3 Options for Improving the Demand-worthiness of Index Insurance

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, as evidenced by the discussion above. 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 build on these suggestions, expanding and combining them into a next 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 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 and minimize prediction error—*i.e.*, the design effects on basis risk are likely large. Fortunately, widely available micro data on farm households allows estimation of a statistically optimal loss function for rainfall or any other candidate signal.[5] 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 used micro data to determine the relatively desirability of rainfall, area yield and satellite-based index insurance contracts.

2.1 Minimizing Design-induced Basis Risk for West African Grain Farmers

In this section, 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 for each household. The goal of a basis risk-minimizing contract is thus to create an

[5] 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.

index that can statistically explain as much of the yield fluctuation faced by households as possible.

One possible index would be simply 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. Using the ICRISAT data, 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 about one half of the yield fluctuations experienced by households can be explained by average village grain yields. The other half represents the basis risk that would be uninsured even under a village-level area yield contract. While it is surprising that as little as one half of the risk may be common across villagers, note that it is precisely this correlated risk that households would have trouble managing 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, 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.[6] 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.

[6] It might also raise problems of moral hazard as villagers might be able to collectively agree to under-produce so that village yields would drop and everyone would receive an insurance payout.

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 signaling 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 pixel). NDVI measures at this resolution are freely available on the FEWS NET (Famine Early Warning System Network) website.[7] 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 2 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.

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

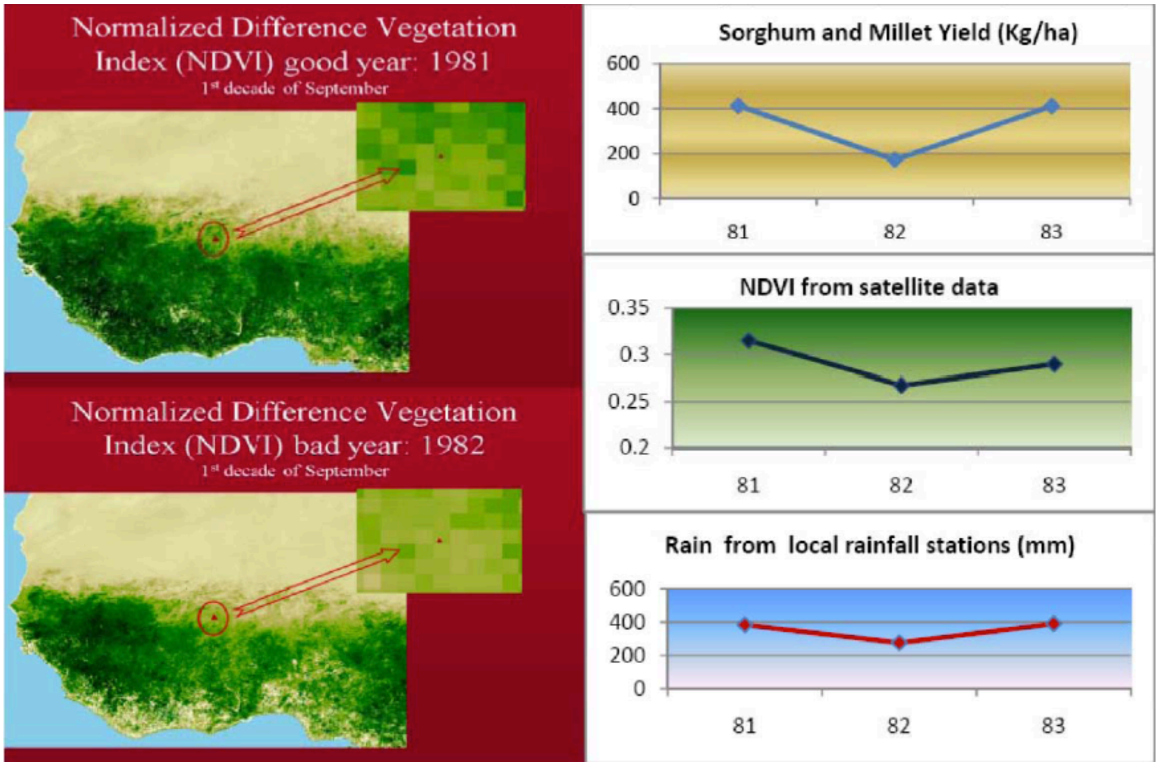

Figure 2 Yield Prediction using Satellite Data

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 employ the transformation of NDVI information called the Vegetation Condition Index (VCI). Suggested by Kogan (1991), an expert in early drought detection 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 3 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 3, 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 relates absolute NDVI values to a local context and therefore 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 75% of the risk reduction of the village level area yield contract. 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.

While it may be possible to improve the predictive power of rainfall data through further analysis, it is important to note that is quite unlikely that any insurance scheme could afford to have the village-level weather measurements that are available in the ICRISAT data. Even the most ambitious proposals for weather station construction suggest that each station would have to cover a circle with a radius of 25 kilometers. By way of comparison, some 30 separate NDVI measurements would be available within a circle of that radius, meaning that a high-density NDVI-based contract should have a further design advantage over weather-based contracts.

While analysis of the ICRISAT data for West Africa suggests that NDVI can not only offer lower basis risk, at lower cost than rainfall based indices, this finding

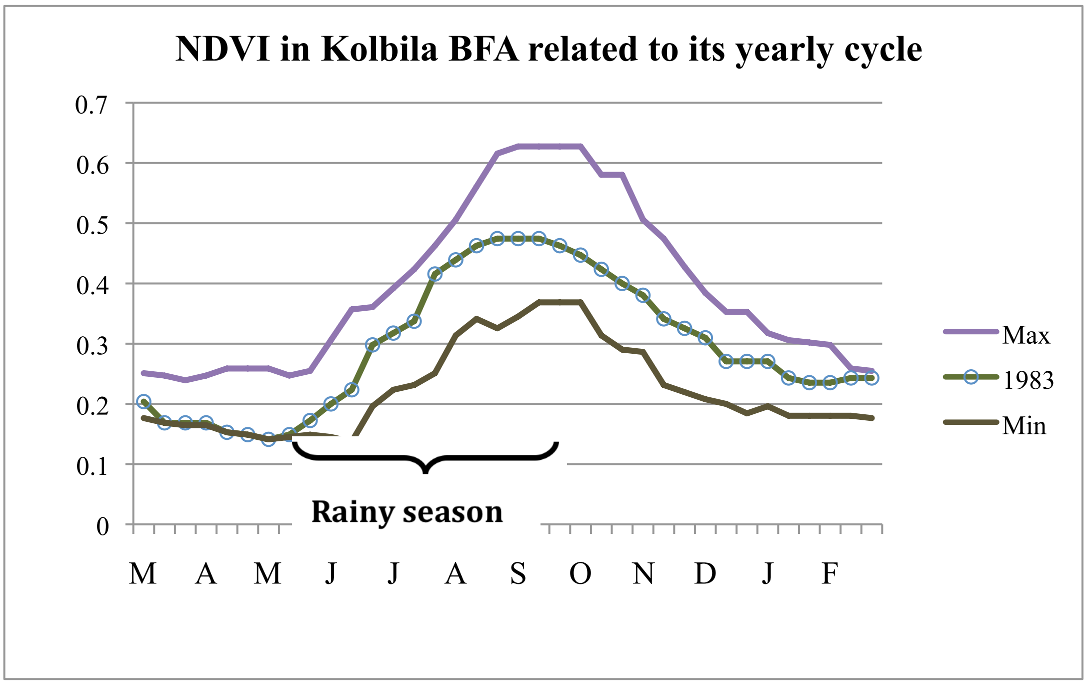

Figure 3 Calculation of VCI using Max and Min NDVI

should not be generalized to other agro-ecological environments. In some situations remote sensing may provide a cost-effective index, as is the case with livestock mortality predictions in Kenya, while in other situations it may prove to be an unreliable predictor of agricultural yields (as was discovered when a satellite information was found to be a poor predictor of cotton yields in Mali). These findings do show that designing a cost-effective index insurance contract that minimizes basis risk should consider a variety of index options by using micro data to ground-truth and select the optimal index. At the same time, the analysis also shows that there are limits to the elimination of basis risk, even through optimal contract design. In the extreme case of the Sahel, it would appear to be difficult to use index insurance to eliminate more than half of the agricultural risk faced by farmers. Given these technical limits to the quality of index insurance, the next section explores the possibility for further improving the development impact value and sustainability of insurance by interlinking it with credit.

Section 3 Interlinking Insurance and Credit

The analysis in Section 1 assumed that the small-scale farm household had access to only one ("traditional") agricultural activity. While the risks associated with such activities are important, development economics has long been preoccupied with the notion that one of the biggest cost of risk is that it induces farm households to 'income smooth" and shy away from riskier, new technologies and economic opportunities that offer improved incomes on average. 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 and fertilizers. 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.

In order to explore the performance of index insurance in combination with new, higher returning technologies, we return to the stylized household model discussed earlier and detailed in the Appendix. We now assume that with significant investment in seeds and fertilizer (equal to the household's non-farm earnings), the household can use an improved technology that increases average net agricultural income by 25% over the traditional cropping activity.

This high returning technology offers the household the prospect of having higher income and therefore higher consumption. But given the input costs and the riskiness of the new technology, this higher average consumption comes at the cost of increased risk.

Under these additional assumptions, our simulation analysis shows that the probability that household consumption falls below 75% of its long-term, *traditional technology* average rises from 10% to nearly 20% if the new technology is adopted without insurance (see Figure A2 in the Appendix). In addition, it brings on a non-trivial probability that consumption could fall as low as 50% of its old long-term average. Even assuming that the household had the savings to finance the high returning activity, this stark tradeoff between risk and return would surely discourage many farmers from adopting the new technology,[8] keeping themselves safe, but also perpetuating a low standard of living.

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 by continuing to utilize the traditional technology carries a very high loading as it reduces expected household income from agriculture by 25% while reducing overall average household consumption. As discussed above, this self-insurance strategy also carries uninsured or basis risk, as the self-insured household still faces 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 on traditional technologies. As the next sections will describe, the mechanisms for doing this will depend critically on the nature of the financial market.

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 small farm households lack the savings to purchase the new technology even if they wanted to. To explore how insurance and credit might interact in this environment, we assume that agricultural loans are offered by a competitive lending sector on

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[8] When analyzed from the conventional economic perspective of expected utility theory, only households with very low degrees of risk aversion or higher than average stores of wealth would adopt the technology (see Carter *et al.*, 2010).

terms that yield lenders expected profits exactly equal to the economy-wide opportunity cost of capital. We also assume 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 to lower wealth households and that empirically, it may constrain the choices and income of up to 20% of small scale in Central and South America are risk rationed.

Under a fully collateralized loan contract, the benefits of index insurance will accrue directly to the household, which carries all risk. The simulation results shown in the appendix indicate that when combined with a loan and an index insurance contract, the new technology can be undertaken with almost no risk of consumption falling below 50% of its long-term average. However, even with interlinked credit and insurance, the household would still face some increase in the risk that consumption falls to less than 75% of its long-term average relative to the self-insurance strategy. Beyond that level, the interlinked contract strongly dominates the self-insurance strategy as a majority 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 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 discussion above assumes 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 or other contract that has minimized design effects. However, in environments where more of the risk is insurable, covariant risk (say two thirds rather than one half), 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 (see Figure A2 in the appendix). That is, compared to the self-insurance strategy, when adopted with and interlinked credit and insurance contract, the high yielding technology offers less risk of low consumption outcomes and much higher chances of high consumption outcome. Even the most risk averse agent would be expected to prefer the interlinked arrangement to the self-insurance of low technology (conditional on understanding and trusting the contract).

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.

3.3 Index Insurance and Credit Supply in High Collateral Environments

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. 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 loans 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 it is potentially of even greater importance.

3.4 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, the lender carries some of the risk of low yield. Assuming lenders are even willing to issue low collateral loans, they will need to charge higher contractual interest rates in order to achieve a given expected rate of return. In addition, because default on agricultural loans are likely to be correlated, lenders are likely to either severely limit the amount of agricultural loans in their portfolio (Tarazano and Trivelli, 2005) and, 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 *et al*. 2010).

In this context, supply of credit to finance new technologies is likely to be restricted and expensive. Moreover, simply offering index insurance to farmers is unlikely to have much of an impact 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. Put differently, neither loan nor insurance markets are likely to independently emerge in low collateral environments, and agricultural technologies and income are likely to stagnate.

Interlinked insurance-credit contracts are one possible way out of this conundrum in low collateral environments. 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 these mechanisms are somewhat different than the high collateral case considered above, according to the analysis of Carter *et al.* (2010), the net result is almost identical in terms of the overall impact on farm incomes and levels of well-being. 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.

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 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 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, both on small farm incomes and on human development outcomes.

Appendix

Simulation Analysis Index Insurance versus Self-Insurance

This appendix provides additional detail on the simulations discussed in Sections 1 and 3. A complete discussion of these simulations, as well as further analysis of the degree to which index contracts would be demanded is given in Carter *et al.* (2010).

Index Insurance with Traditional Technology Only

Figure A1 below illustrates the risk faced by this stylized farming household both with and without index insurance, assuming the opportunity set is unchanged. 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.

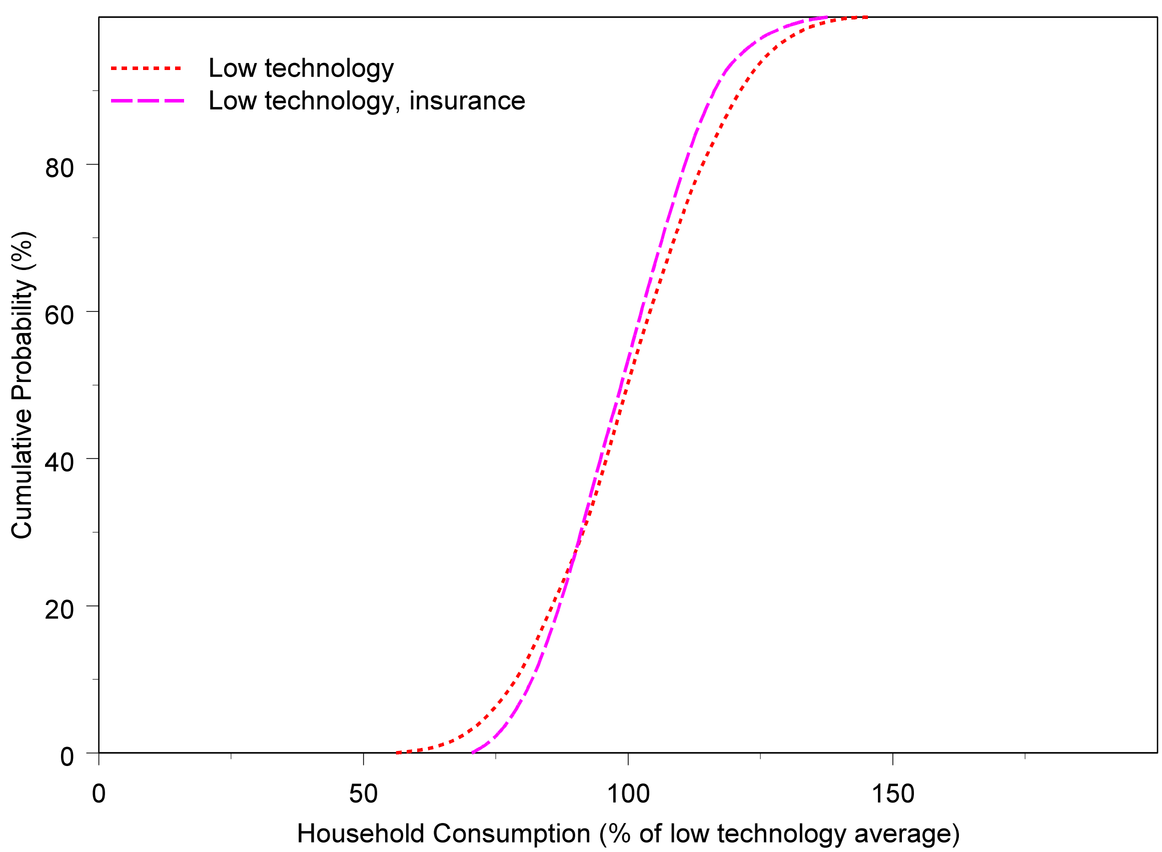

Figure A1: Insuring the Traditional Technology

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. 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 A1 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 basis risk would stabilize household consumption at its mean level (less markup or loading costs). As can be seen from Figure A1, 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. The partial reduction in the probability of low outcomes is purchased at the cost of reduced average income.

Index Insurance and High Return Economic Activities

Figure A2 illustrates the cumulative distribution function for the stylized high returning activity described in Section 3 above. Compared to the traditional activity (shown here, as in Figure A1, as the red small-dash line), the high returning activity has mean returns that are 25% higher than the traditional agricultural activity and requires the purchase of significant cash inputs. The solid black line in Figure A2 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.

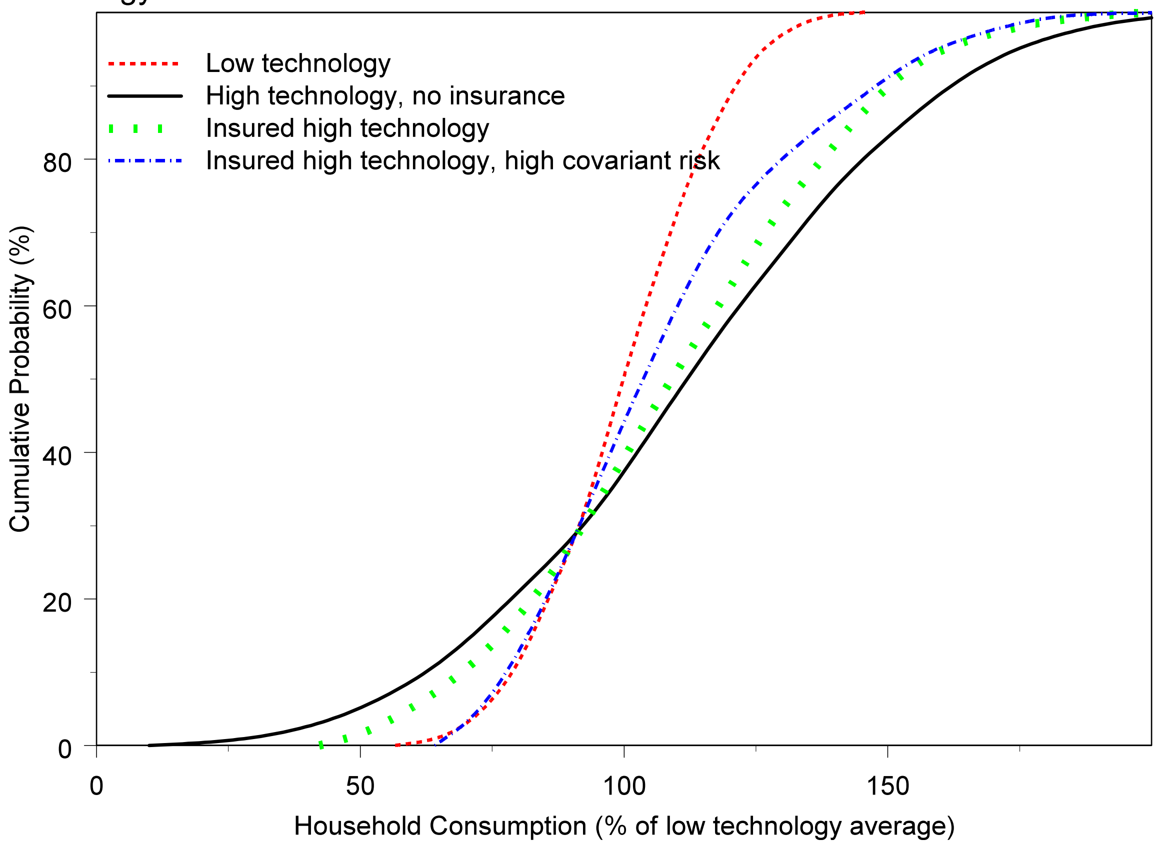

Figure A2 Interlinking Insurance and Credit for Technology Uptake

The green dotted line in Figure A2 shows the impact of index insurance when interlinked with credit and technology uptake in a relatively unfavorable agro-ecological environment in which only 50% of the risk faced by households can be covered by a well-designed index insurance contract. Despite this disadvantage, this interlinked insurance arrangement pushes the risk of low consumption outcomes back towards the levels under the traditional, low returning technology. At the same time, the interlinked adoption of the new technology outperforms self-insurance strategy 70% of the time. While this interlinked contract still presents the household with a tradeoff (higher returns at some increased risk of low outcomes), the tradeoff is less severe than that offered by the high technology without insurance.

Finally, as shown by the blue line in Figure A2, interlinked adoption of the new technology can completely dominate self-insurance if more (tow thirds) of the overall risk faced by households is insurable, covariant risk.

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