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SUBJECT: Using Satellite Imagery as the Basis for Index Insurance Contracts in West Africa

In our memo of last June, we discussed the logic of matching technological innovations with financial innovations that insulate farmers from the risks that shadow dryland West African agriculture. One such innovation is index insurance[1] that can potentially:

1. Crowd-in credit by removing the systemic risk that discourages agricultural lending, especially by micro-finance institutions (Carter 2008);
2. Enhance farmer's willingness to adopt higher yielding technologies that require greater up-front investment
3. Smooth out farmer's income across good years and bad years so that …

Realization of this potential requires an index that can be:

1. Covers sufficient risk [footnote on basis risk as uncovered]
2. Can be delivered at low cost to the small farm sector

While there are a number of candidate indexes (area yield indexes; rainfall and other weather indexes), our research over the last few months reveals that insurance indexes based on remotely sensed measures of vegetative growth can meet these two critical requirements. The remainder of this memo summarizes our work to date.

The Normalized Difference Vegetation Index

The Normalized Difference Vegetation Index (NDVI) is a remote measure of vegetation density. NDVI is scaled to go 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

[1] Conventional insurance (that indemnifies the insured based on their individual losses) has proven to be non-implementable in small scale agriculture. Costs of verifying losses for small contracts are prohibitive, leaving such insurance vulnerable to severe incentive problems that destroy the ability of the market to provide it. In contrast, index insurance issues indemnity payments based on a single, easy to observe indicator that cannot be influenced by any single individual acting in isolation (*e.g.*, rainfall, or satellite imagery of ground cover).

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.[2] 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: Illustration of yield prediction using satellite data

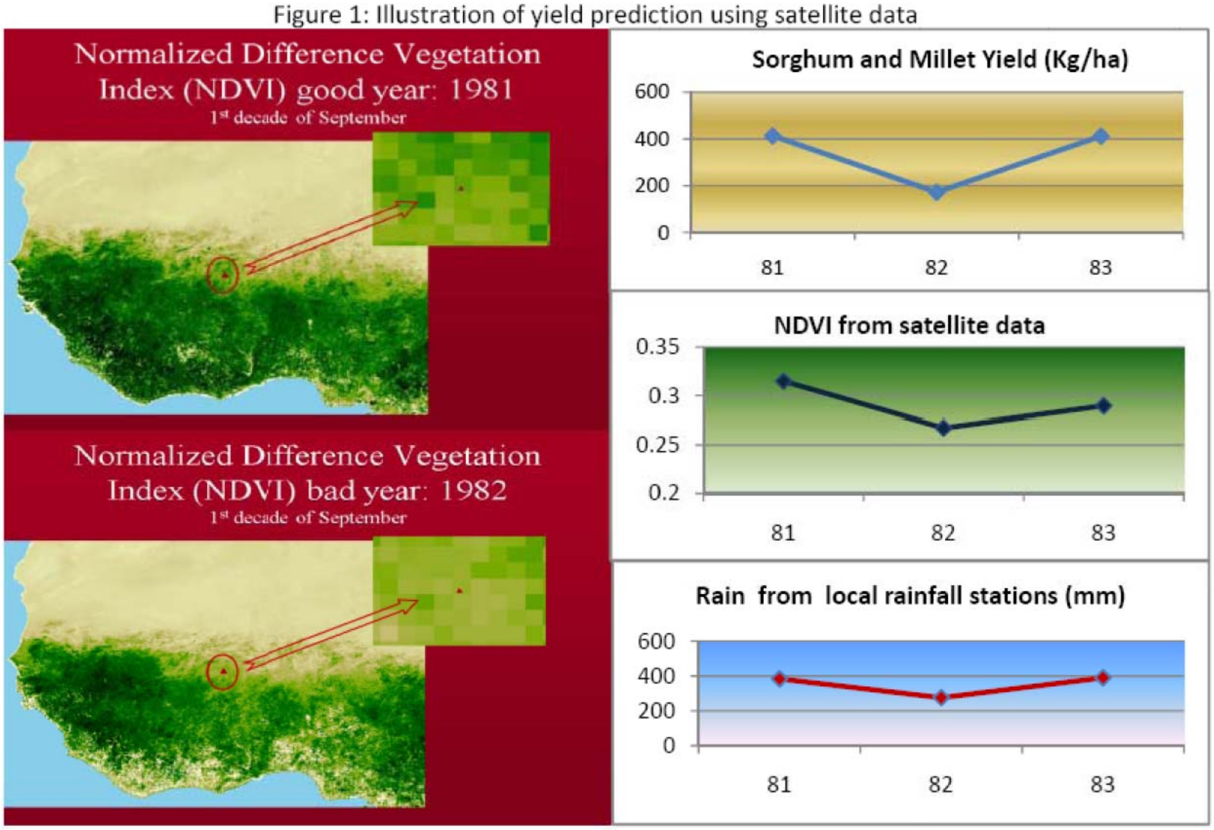

Figure 1 illustrates how NDVI works. The diagrams on the left side of the figure display actual NDVI data for West Africa. A brown to green color spectrum has been used to graphically display NDVI, with browner colors signaling low NDVI values and greener colors high NDVI values. The insert in each diagram shows the individual 8 km square pixels for the region surrounding the village of Silgey 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

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

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.

Response Function Analysis

So what precision can be obtained with NDVI? To answer this question, we estimated an optimal response function that uses NDVI signals to best predict individual farmer grain yields. To estimate this response function and explore the potential of NDVI, we relied upon the high quality data collected by the ICRISAT Village Level Studies carried out in 6 communities in Burkina Faso over the 1981-1985 period (detailed yield data were collected only for the first three years of the VLS). In each village, 25 households were surveyed with extensive plot level information collected every two weeks.

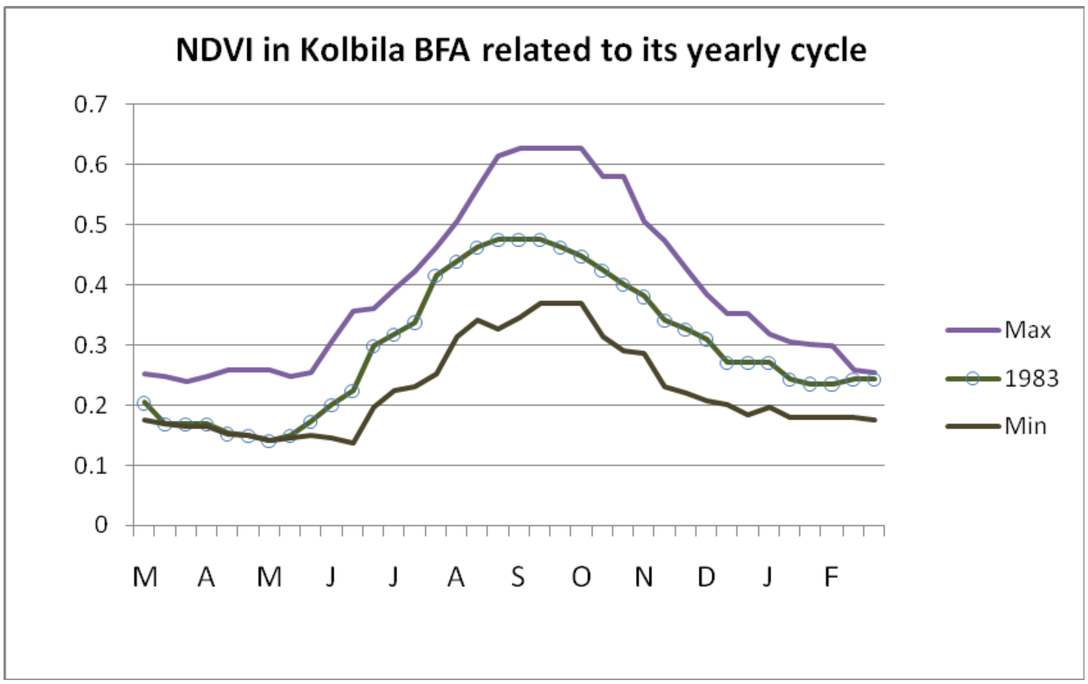

Figure 2: Calculation of VCI using Max and Min NDVI

After analyzing a series of options, we found that the best predictor of yields for the ICRISAT VLS data is obtained by employing a transformation of NDVI information called the Vegetation Condition Index (VCI). Suggested by Felix N Kogan, an expert in early drought detection and watch from NOAA, VCI is defined as:

$$VCI=100*(NDVI - NDVImin)/(NDVImax - NDVImin)$$

Basically, 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. For example in Figure 2 the VCI would be close to zero in April but around one half in September. This methodology facilitates the use of NDVI data coming from heterogeneous places in the region.

Once we have calculated the most interested pieces of information are the VCI before and after the rainy season with the idea that if the vegetation increased a lot during the rainy season then the conditions have also been favorable for the crops. We now show the preliminary results of our estimation of this relationship.

Table 2 presents regression results derived from the ICRISAT VLS data. The unit of observation is household level grain yields[3] and the different regressions explore how well those household level yields can be predicted with the kind of information that could be used as the basis for an insurance index. All regressions include a 'household fixed effect' term which controls for the long-term average yields of each household.

The first regression in Table 2 includes only these household fixed effects and obtains an R-squared of 0.57, meaning that time-invariant characteristics proper to each households explain 57% of the variation in yields, and the remaining 43% correspond to random shocks affecting the households (as well as changes over time in household characteristics). This 43% is an upper bound estimate of the magnitude of the risk that households are unable to manage through plot scattering and other self insurance mechanisms.

The second regression in Table 2 shows how much of this remaining yield variation could be insured with an area yield index specific to each village. It does this by including a dummy variable for each village-year combination. The coefficients of these dummy variables are the equivalent of an area yield index calculated separately for each village and each year. The R-squared for this regression rises to 0.705. This village specific area yield index is picking up no less than a third of the uninsured risk that households face.

Because a village specific yield index would be extremely costly to implement, the key question is whether NDVI information for each village can be used to obtain a similar predictive power. The answer turns out to be yes. As shown in column 3 of Table 2, including the two VCI measures described above in the regressions results in an R-squared almost identical to that obtainable with the area yield index (0.690 versus 0.705). This is an astounding finding as the NDVI data on which the VCI measures are based is freely available in real time.[4]

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[3] The household level grain yield is a weighted average of the yields the household obtains across its various plots. Note that this household average is itself partially smoothed against weather fluctuations to the extent that households successfully employ field scattering and the other self-insurance devices discussed in Carter (1993).

[4] Effectively, NDVI is covering 89% of the covariant shocks covered by the village level area yield index.

The final regression reported in Table 2 shows the NDVI-based measures slightly out-predict the village level rainfall data collected by ICRISAT.[5]

Table 2 : Yield predictions					
	1	2	3	4	5
	Yield	Yield	Yield	Yield	Yield
VCI rainy season			370.13		364.37
			[7.31]***		[3.25]***
VCI dry season			-491.32		-483.46
			[4.10]***		[3.97]***
Rainfall				2.39	0.04
				[5.34]***	[0.06]
Vlge*time fixed effects	N	Y	N	N	N
Household fixed effects	Y	Y	Y	Y	Y
Observations	281	281	281	281	281
R-squared	0.567	0.705	0.69	0.677	0.69
Absolute value of t statistics in brackets					
*** significant at 10%; ** significant at 5%; *** significant at 1%**					

Preliminary Contract and Pricing

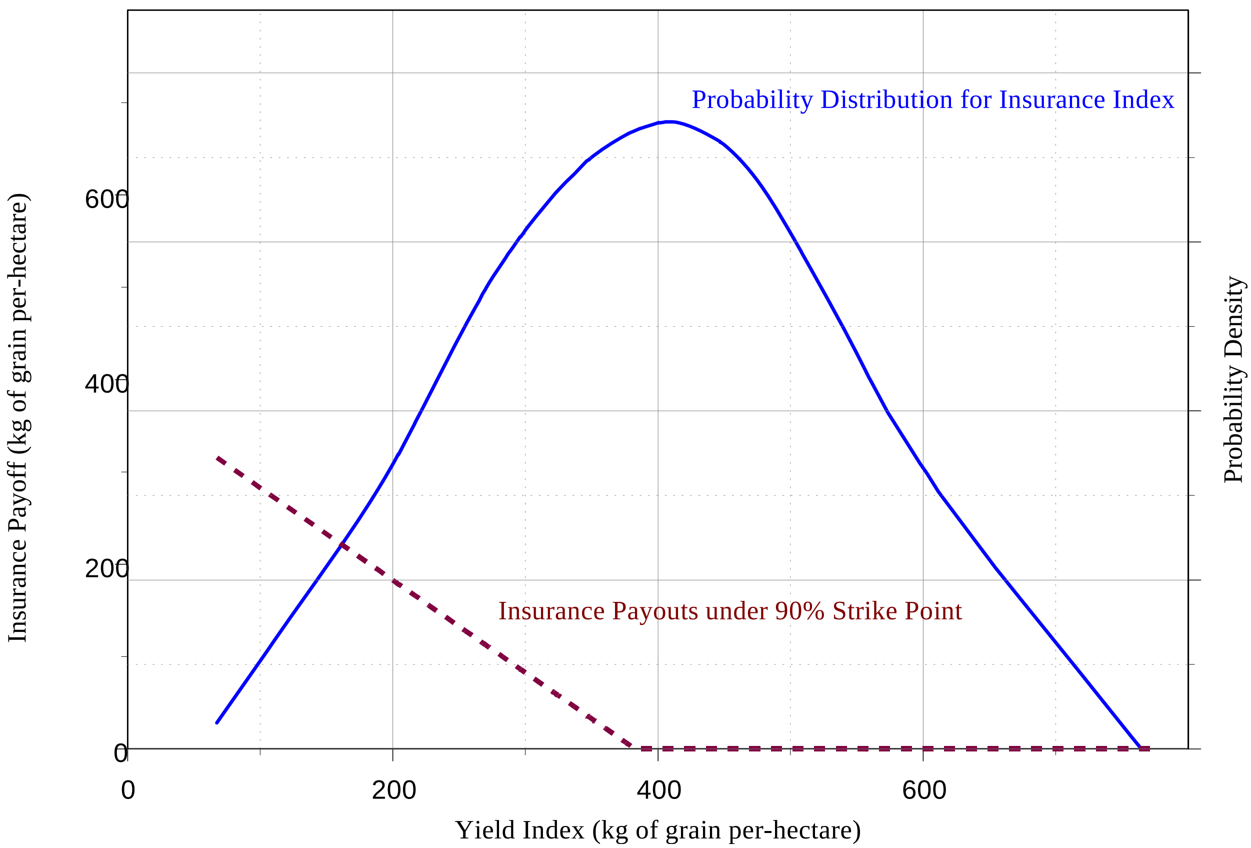
The regression or NDVI response function presented in column 3 of Table 2 above forms the basis for an optimal yield insurance index. Using the almost thirty years of NDVI information, we used the estimated response function to create a time series of predicted average yields for Silgey. We in turn used that predicted data to estimate the probability distribution function shown in Figure 3. With this information, we are now in a position to design and price an index insurance contract for Silgey producers.

The solid line in Figure 3 displays the payoff function for a index insurance contract that has a "strike point" equal to 90% of long-run average yields. As long-term yields for Silgey are roughly 425 kg/Hecate, this strike point is at 383 kg perh-hecatare. The strike point is the predicted yield index level at which payoffs begin to the insured. As the predicted yields fall further below the strike point, indemnity payments to the insure increase and are always sufficient to bring the borrowers gross income back to the level that would have been achieved

[5] We need to keep in mind limitations of the analysis to date. First it is based on data covering only 6 villages and 3 years, the access to data with a higher coverage in time and space are necessary to provide more reliable results. Second, the producers were using a traditional technology and very little fertilizer, the introduction of modern agricultural technologies may modify the relation between crop growth and weather conditions in many different ways, hence the need to work in partnership with agricultural researchers to design an insurance mechanism that would embrace such changes. This partnership would aim to find the best way to offer Sahelian farmers access to better agricultural technologies, and allow them to get the best out of it thanks to microcredit and insurance.

had yields been at the 90% level. For example, if the NDVI measures predict average yields of 320 kg/hectare (or about 75% of the long term average), then the insured producer would receive payments equal to the value of 53 kg/hectare. Note that any individual farmer will not experience losses identically equal to 53 kg/hectare, but the prior analysis indicates that this should be a good estimate of the farmer's individual losses.

Figure 3: Index Insurance Contract for Silgey



We are currently in the process of calculating the cost of this index insurance contract. The actuarially fair, or pure, premium is the price that just equals the expected or average payouts under the contract. This price will of course be higher for higher strike points and lower for lower strike points. Regions with greater (lower) risk will also have higher (lower) pure premia. The market price that a private insurance provider would charge would be typically marked by some additional percentage to cover the costs of administering the contract.

Next Steps to Explore Technological and Financial Innovations

It is one thing to implement index insurance well following the strategies outlined in the prior section. It is another thing to confirm that well-implemented insurance has the positive impacts expected to accompany it. Our core hypothesis is that index insurance can enable a virtuous circle of increased uptake of productive technologies, enhanced accumulation of productive assets (including the human capital of the next generation) and deeper rural financial markets.

A particularly compelling way to test this hypothesis and the magnitude of these synergistic effects is to piggyback an index insurance pilot with CCRP programs designed to enhance technological options for poor and small-scale farmers. A joint study design would permit evaluation of the following four regimes:

Table 2: Experimental Regimes to be Evaluated

	Without Index Insurance	***With Index Insurance***
Without Technology Package	***Regime 1*** (Control Locations)	***Regime 2*** (Insurance Only)
With Technology Package	***Regime 3*** (Technology Only)	**Regime 4** (Synergistic Locations)

The core hypothesis is that regime 4 households will outperform the other regimes in the short and especially the long-term when examined using both economic and human development metrics. Credible evaluation of this hypothesis would require randomized allocation of otherwise similar households or communities across the different regimes. Building on our prior experience, this would be achieved through either a randomized rollout strategy or through an encouragement design.[6]

Regime 2 in the table above is also quite interesting in its own right as it would allow exploration of the degree to which removal of correlated risk by itself would suffice to crowd-in technological change (and the finance needed to implement it). One option we are exploring is to broker an index insurance and ag micro-finance package, with the former being used to leverage in the latter. Randomization methods would again be used to permit reliable inference on the impact of the financial innovation on the speed and sustainability of technological diffusion.

While implementation of insurance requires resolution of other issues (e.g., farmer education, creation of trust in the insurance contract, etc.), we hope that this memo manages to communicate the feasibility of index insurance to realize the goals discussed in more detail in our prior memo.

[6] An encouragement design randomizes the provision of *incentives* to participate in a program. It is typically used when it is not feasible to maintain a strict separation between treatment and control groups. In the BASIS Pisco cotton insurance pilot, coupons that lower the premium and invitations to educational sessions were randomly offered to farmers because (quite reasonably) the MFI was not willing to deny insurance to qualified, but "control-group" farmers.

References

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