BASIS

Index Insurance 4 Innovation Initiative

Developing a Satellite based Index to Predict Crop Yields in Smallholder Agriculture

Introduction

We propose to develop an innovative satellite based index which can reliably predict local crop yields. This work is the centerpiece of a larger project to design an index insurance contract that can successfully protect smallholder farmers against negative covariant shocks such as droughts and floods. While there currently exist several rainfall based insurance products on the market, such contracts suffer from a lack of historical data, poor coverage for farmers and high scaling costs. Rather than relying on data from weather stations, our proposed product utilizes satellite based indicators of local yields, such as an index of vegetation density and plant transpiration, which have been shown to correlate well with observed biomass and crop yields.

The main advantage of using satellite data is the availability of risk density data over space and time at a very low cost. This makes it possible to price the insurance risk very accurately, which is often a key requirement by reinsurance companies. The second benefit of using satellite data is the ability to better predict local yields resulting in lower basis risk for farmers. These data can be disaggregated to the size of a pixel (250x250m), which is equivalent to having a weather station for every 6 hectares, or more than 3,000 weather stations in a 20km by 10km area. Also, as opposed to rainfall, which is only indirectly related to yields, the satellite based indicators are directly related to crop outcomes. Finally, a satellite based contract is more easily scalable due to the high availability of data.

While the ultimate purpose of this project is to create an index insurance contract that can be offered to farmers as part of an interlinked credit/insurance product, the scope of this proposal is limited to the development of a satellite based crop yield model. If we are able to establish a strong correlation between our satellite based index and crop yields, we will be poised to design a crop index insurance contract that will provide far better protection for farmers than existing weather based contracts.

Literature Review

An overwhelming body of literature has left no doubt that risk poses one of the greatest threats to development in low-income economies. Particularly small scale farmers are plagued by risk, as weather variation is the largest source of risk in agriculture (Cole and Giné 2010; Giné and Yang 2009) and because such risk is spatially correlated, making local risk sharing mechanisms ineffective and affecting everyone in the community. While index insurance offers a compelling solution to the problem of covariant risk, these products have generally suffered from low demand. For example, Cole and Giné (2010) find that the adoption rate for a rainfall based index insurance product offered to smallholder farmers in two regions in India is close to zero. This somewhat disconcerting observation has prompted several empirical and experimental studies attempting to isolate the determinants of the demand for index insurance.

While this evidence suggests that price, liquidity, interlinkage with credit, and trust all have an effect on demand, the literature has paid little attention to the problem of basis risk[1]. A few papers point to basis risk as possibly explaining low uptake rates (Giné and Yang 2009; Smith and Watts 2009); however, empirical evidence on its effect on demand is lacking (Giné et al. 2010). Nevertheless, theoretical models suggest that a higher level of basis risk decreases demand for insurance (Clarke 2010), thus reducing the value of an interlinked index insurance and credit contract and potentially making such a contract less attractive than non-interlinked insurance and self-insurance strategies (Carter et al. 2011). While these results are based on standard expected utility models, basis risk might also have behavioral effects. For example, an ongoing project in Mali is studying how ambiguity aversion can make index insurance undesirable for farmers when basis risk is high, as farmers are faced with a compound lottery in which both a weather event and the insurance payout are stochastic (De Bock et al. 2010).

Despite the importance of basis risk, index insurance projects in developing countries have almost exclusively used precipitation-based indices, which have been shown to carry a relatively high level of basis risk, with correlations between precipitation and biomass growth at the weather station ranging from .26 to .70 (Sims and Singh, 1978; Price et al., 1998). Even lower correlations have been reported for the link between rainfall indexes and crop production (Martyniak 2007; Staggenborg et al. 2008). Making matters worse, weather stations are typically sparse and the agro-climatic landscape in Sub-Saharan Africa is generally quite heterogeneous, with the result that basis risk increases sharply with distance from the weather station. Smith and Watts (2009) show that if the spatial correlation between yields at two farms is .5, the correlation between the precipitation index and yields at the farm located some distance away from the weather station would be .35 or lower. Moreover, their simulation results indicate that in this scenario, there is approximately a 60% probability that a farmer experiencing a severe yield loss (yields less than 50% of average) will receive no indemnity payout. These observations prompt the need for more innovative insurance contracts and further empirical research on the impact of basis risk.

An idea that has received surprisingly little attention in the literature is to use a satellite based index, such as the Normalized Difference Vegetation Index (NDVI) or evapotranspiration (ET) as a basis for payouts. Giné et al. (2010) suggest that such an index is likely to have less basis risk than a rainfall based index and a few informal studies provide some evidence of this (Carter and Laajaj, 2009). In addition, several studies from the remote sensing literature have found varying levels of correlation between satellite based indices and observed crop yields. For example, Rosema (1993) develops a sophisticated model of evapotranspiration to simulate crop yields and tests her predictions against several years of recorded biomass observations for 25 sites in Mali. While she finds a relatively low R squared (.2) using farm level data, a much stronger correlation (R squared between .68 and .84) was found when using an improved version of her model to predict maize yields in Zambia and Zimbabwe both at a provincial and at communal level for the years 1994-1997 (EARS, 2012). Using a satellite based measure of water use efficiency (WUE) and radiation use efficiency (RUE) to model wheat yield in India, Bhattacharaya et al. (2011) finds an R squared of .81 and .64 when comparing predicted yields from the RUE model and the WUE model, respectively, to district level average yield statistics for three seasons (2002/03-2004/05) in twelve selected wheat growing districts within four agroclimatic zones in India.

While a large number of studies have used various satellite based measures to predict crop yields, most of these are relying on county level data or experimental plot data over a short time period to validate

[1] Basis risk is the risk faced by the producer that is not covered by the contract (see Carter 2011 for a discussion of basis risk, its constituent parts and its relationship to index design).

their models. We propose estimating our models using a combination of self-reported yield data from existing longitudinal household surveys and from historic recall data. This allows us to test our model over a large range of agroclimatic conditions, which is particularly important since the model will be primarily used for the detection of extreme weather.

Proposed Methodology

The primary innovation of this project will be to develop an index that reliably predicts crop yields at the local level. While previous work has attempted to do this using weather data, we plan to use a series of satellite based indicators that have been shown to correlate well with observed biomass growth and yields. The process of developing a satellite based yield model will be divided into three phases: 1) creation of the index; 2) collection of actual yield data; and 3) estimation of the yield model. We expect to be able to carry out phases one and two simultaneously before starting the final phase.

In the first phase, we will create a series of indices based on available satellite data. Currently, we are considering using four different types of satellite based indices: 1) Normalized Difference Vegetation Index (NDVI); 2) Evapotranspiration (ET); 3) Green Leaf Area Index (GLAI); and 4) satellite based weather indices[2]. While such satellite data is available in raw form from various online sources, the process of acquiring such data and converting them into a useful index requires massive computing power and specialized software. We are thus planning to collaborate with a company called the SI organization, which has agreed to provide satellite based indicators for our pilot areas against a fee. Their system capabilities will allow us to utilize the most high-resolution high-frequency data available, and their expertise will be vital in developing more complex indicators such as a measure of evapotranspiration.

Also, as part of the first phase, we will work with the SI organization to develop a model to identify specific crop areas over time. To facilitate this work, we will trace the boundaries of established paddy areas and record GPS coordinates. Finally, to ensure our satellite data are consistent with local conditions, we plan to collect several types of ground level data. Specifically, we will use a spectrometer to measure the actual NDVI profile of paddy in local demo plots. Also, to better make use of our evapotranspiration index, we will measure local evaporation, and we will calibrate the index to local weather data from existing weather stations.

In the second phase, we will be gathering data on observed yields in the field. To obtain the detailed multi-year crop yield data necessary to estimate our yield model, we are currently considering a three-pronged approach.

First, we have already identified some existing panel datasets based on a series of elaborate agricultural household surveys in multiple places across East Africa. These will allow us to extract historic plot level yield data which can be mapped to satellite images for that same area.

Our second approach is to collect our own historic yield data (based on recall) and corresponding map location of fields from farmers in several locations in Tanzania. We have already collected such yield data for paddy in a pilot area near the town of Same in Northeastern Tanzania through our partnership with World Vision Tanzania. We are also poised to conduct a similar survey in two of World Vision's Area

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[2] NDVI provides a measure of vegetation density and has been shown to correlate well with actual yields for a variety of crops. ET is a satellite based estimate of the amount of plant transpiration and surface evaporation. GLAI is a measure of the total green leaf area per a given section of ground area. Satellite based weather indices include estimates of rainfall, cloud cover, temperature etc.

Development Programmes (ADPs) near the town of Singida in the North central part of Tanzania, and in two additional ADPs near Same. There is also a possibility that we will be able to collect data from paddy farmers who are part of an outgrower scheme near Kilombero Plantations Limited (KPL) in South central Tanzania through a potential future partnership with USAID Tanzania.

Finally, for additional calibration, we will set up local demo plots and measure the biomass growth throughout the season and final yields at harvest. These data will be compared to the spectrometer measurements referenced above.

In the final phase, we plan to use the satellite based data acquired in the first phase and the yield data gathered in the second phase to develop and estimate a predictive yield model. This model will be calibrated to local conditions and should most importantly be able to accurately predict extreme yield shortfalls, such as those caused by droughts and floods. We plan to experiment with different types of indices (or combination of indices), levels of spatial aggregation, and model specifications in order to identify a model that best predicts crop yields.

In addition to this core design contribution, another key innovation of the proposed project will be to make the satellite-based index scalable. We will estimate a meta-model in which the parameters of the yield model can be expressed as a function of observable agro-ecological factors by pooling NDVI/evapotranspiration yield models estimated across a variety of East African locations where good data are available. The ability to accurately estimate such a meta-model will be absolutely vital if the promise of index insurance is to be cost-effectively rolled out across broader geographies than intensely studied pilot zones.

Outreach and Dissemination

If we are successful at developing a satellite based yield model that accurately predicts yield shortfalls due to covariant weather shocks, we are in a strong position to design an index insurance contract that can eventually be offered to farmers through local private companies not only in Tanzania, but also in other parts of the developing world. As a first step, we will seek opportunities to present our findings at various policy and programmatic discussions with implementation partners, particularly USAID. Further, we will pursue opportunities to contribute to the ongoing dialogue in USAID and other implementation organizations regarding tools and strategies to improve resilience and promote adaptation to global climate change.

Timeline

	2013											
Activity	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Acquire satellite based data and create index	■	■	■	■								
Conduct retrospective yield survey	■	■										
Identify crop areas	■	■										
Clean and prepare yield survey data			■	■								
Collect data from demo plots				■	■	■						
Estimate crop yield model				■	■	■						

Budget:

Description		Cost
Acquisition and analysis of satellite data (from SI organization)	$	69,000
Retrospective yield survey	$	6,000
Travel to Tanzania (3 trips, 14 days each) (Airfare, hotel, allowance)	$	10,000
Domestic Travel (1 trip to present results at workshop)	$	2,000
Domestic Travel (1 trip for 2 people to consult with SI)	$	2,000
Equipment (GPS devices, spectrometers etc.)	$	3,000
UCD Indirects (54% on first $25,000; 26% for remainder)	**$**	**$30,920**
Total Budgeted Costs	**$**	**$122,920**

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