Developing Advanced Index-Insurance Products for Ghanaian Smallholder Farmers

A proposal submitted by The Catholic University of America to the Feed the Future Innovation Lab for Assets and Market Access at the University of California at Davis

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I. Introduction

Agricultural development remains an important component of the overall development strategy of Ghana and other agrarian economies in sub-Saharan Africa. The agricultural sector contributes 23% of GPD and over 50% of employment in Ghana as of 2012 (Ghana Statistical Service 2014). Furthermore, the agricultural sector is typically dominated by smallholder farmers using rain-fed agricultural practices on plots often less than one hectare (FAO 2015; Ministry of Food and Agriculture 2012). Smallholder agriculture provides incomes for a significant proportion of the African population and is the primary producer of food for the continent. Therefore, improving yields, incomes, and livelihoods among smallholder farmers in sub-Saharan Africa has the potential to significantly reduce poverty, food insecurity, and improve economic growth.

Among the many barriers to productive and profitable smallholder agriculture in sub-Saharan Africa is risk. Smallholder agricultural production faces numerous risks such as droughts, hail, strong winds, and other adverse weather shocks as well as pests, diseases, livestock damage, and price fluctuations. Agricultural production risks reduce investment in advanced production technologies (Cole et al. 2013, Karlan 2014) and can serve as a barrier to access to the credit needed to finance investments in agriculture (Mishra et al. 2018, Miranda and Farrin 2015, Carter et al. 2016). Therefore, managing risk has the potential to significantly improve farmer incomes, yields, and welfare.

A risk management tool with tremendous potential to manage smallholder risks in a cost effective way is index insurance. By making payouts based on an objective index, index insurance avoids moral hazard, adverse selection, and high transaction costs that make indemnity insurance infeasible for smallholder farmers (Miranda and Farrin 2012). However, results have been mixed regarding demand for and adoption of index insurance despite robust evidence of positive impacts of adoption on advanced production technologies, credit access, and welfare (Karlan 2014; Cole et al. 2013; Mishra et al. 2018; Mobarak and Rosenzweig 2013; Cai et al. 2015; Elabed and Carter 2015). The critical barrier to improved adoption of index insurance is basis risk. Basis risk is the imperfect correlation between the insurance index and the policyholder's yields. Basis risk reduces demand among risk averse and ambiguity averse agents who wish to avoid the prospect of paying for insurance and then suffering losses without a commensurate insurance payout (Carter 2011; Carter, Elabed and Serfilippi 2015; Clark 2016). Insurance policies with significant basis risk are comparable to than expensive lottery tickets that confer little benefit to risk averse policyholders even at actuarially fair prices.

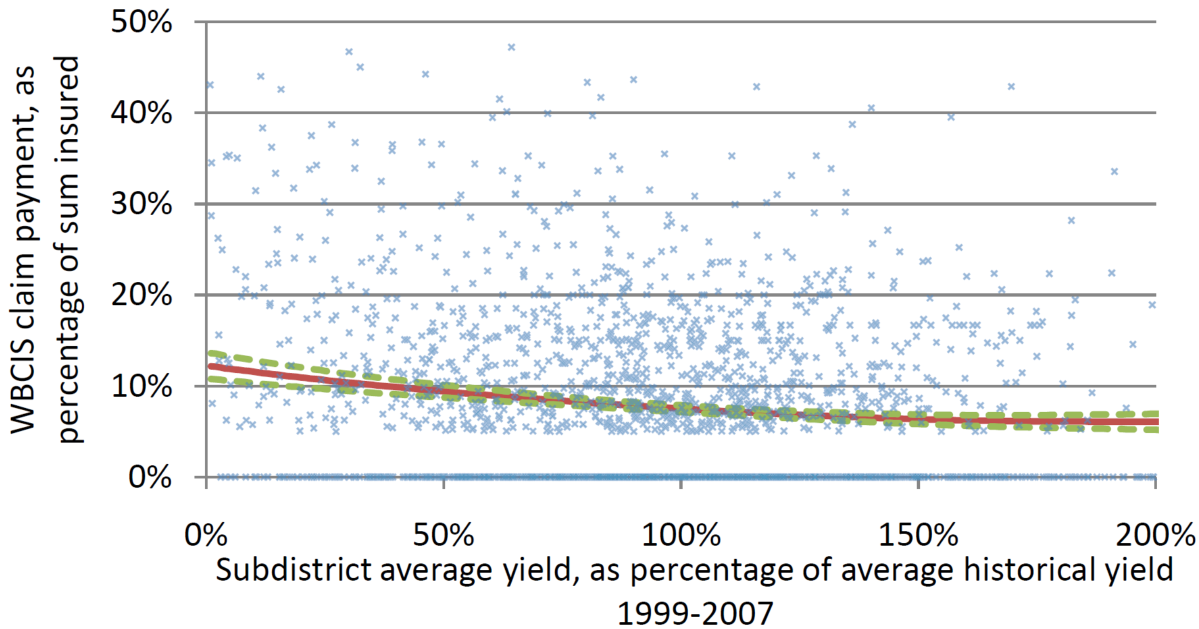
In this project, we propose to develop index insurance policies that minimize basis risk to improve demand and impact of index insurance in Ghana. We plan to use household, remote sensing, and other regional data sources to produce multiple indices and index insurance products that improve the performance of index insurance in the country. Specifically, we first intend to develop advanced area yield indices using remote sensing data and calibrated using household level data from northern Ghana. Next we will develop price indices using regional price data and combine these with area yield indices to create area revenue indices. Then we will develop revenue index insurance products. Finally, we intend to market our advanced products and evaluate demand.

II. The Need for Improved Area Yields

Basis risk poses perhaps the greatest threat to demand for and effectiveness of index insurance policies. Basis risk is composed of two components, idiosyncratic risk and design risk. Idiosyncratic risk refers to deviations between the insurance zone average yields and individual farmer yields. Design risk refers to deviations of the index from the insurance zone average yields.

The agricultural index insurance policy that minimizes basis risk is an area yield policy, which directly insures covariant production shocks within insurance zones and eliminates design risk from the insurance contract. Area yield index insurance policies are rarely implemented in practice due to the high cost of collecting high quality area yield data. Alternatively, the majority of crop index insurance policies to date have been based on rainfall measurements, relying on rainfall stations or more recently, satellite based estimates of rainfall. Area rainfall measures are then taken as a proxy for area yields. However, rainfall based index insurance policies are notoriously riddled with basis risk, particularly design risk, as rain is not always the leading indicator of area yields, rainfall variations can be substantial within insurance zones, and rainfall measurements are often inaccurate at capturing area rainfall. A telling example comes from India's well-know and large-scale Weather Based Crop Insurance Scheme (WBCIS). Clarke et al. (2012) documents the extent of basis risk in these rainfall-based index insurance policies and finds a startlingly low level of correlation between yields and the index. Figure 1, drawn from Clarke et al. (2012), presents insurance claims plotted against area yields over the period from 1999 to 2007. Clarke et al. demonstrate here that these rainfall based index insurance policies offer payouts that have very weak correlation with actual losses, suggesting extreme levels of basis risk and offering farmers very little in terms of valuable insurance protection. If the WBCIS policies are at all indicative of rainfall-based policies to date, then index insurance will need to be significantly improved before we can hope for insurance to experience strong demand and significant impact.

Figure 1: Rainfall Based Index Insurance Performance in India (from Clarke et al. 2012)



The blue scatter plot represents the "empirical joint distribution of claim payments and area years" while the red curve repsresents the "kernal plot of the average claim payments conditional on the yield" (Clarke et al. 2012).

A promising alternative to rainfall-based indices is to use remote sensing data to develop direct estimates of area yield. Remote sensing technology has developed rapidly in recent years and now offers rich data sets of high-resolution images for locations across the globe. Furthermore, by combining remote sensing data with geolocated agricultural yields, researchers can develop models that map remote sensing data to yields and can achieve significant reductions in design risk relative to rainfall-based measures. Furthermore, high-resolution remote sensing data allows researchers to carefully design and adjust the insurance zone sizes in order to optimally reduce idiosyncratic risks. In this project, we intend to pair with a leading remote sensing research team and use geolocated yield data from northern Ghana to develop improved area yield index insurance policies. We will also explore innovative contract features such as a second stage audit, which would allow policyholders to petition for an assessment of losses if they believe they have experienced a downside basis-risk-event (losses with no insurance payout). Conditional audits help remote sensing based products to further approximate area yield contracts yet at a fraction of the price of collecting actual area yield data (Flatnes and Carter 2015).

III. Agricultural Prices and Basis Risk

As we identified above, basis-risk stands as perhaps the central barrier to adoption of agricultural index insurance in developing counties. The problem may be worse when we reconsider how we define basis risk. The standard definition is the imperfect correlation between the index and policyholder yields. However, it is not yields, per se, that farmers are interested in; rather, it is incomes. By focusing exclusively on yields, we effectively treat yields as a proxy for income. However, yields will be an imperfect proxy because incomes are a function of yields and prices. Without considering price variation, index insurance policies may have more basis risk than previously imagined. Even a perfectly designed area yield contract will only capture a component of the area income, the true outcome that we wish to insure. For example, an area yield index insurance product will be of little value to a farmer if a reduction in yields is compensated for by a corresponding increase in local crop prices.

With this consideration in mind, we propose to design a revenue index insurance policy that is marketable to smallholder farmers in Ghana. A revenue index insurance policy makes payouts when a revenue index, composed of both yields and prices, drops below a pre-determined trigger level. The revenue insurance policy will combine the high quality area yield measures with a price index. Our hope is to design an insurance policy that will minimize basis risk, where basis risk is defined as the imperfect correlation between farmer incomes and the index. The effectiveness of an area revenue contract has been demonstrated in the developed world. In the United States, the Group Risk Income Protection program, an index insurance policy designed to protect against revenue shortfalls, has significantly outperformed alternative yield based index insurance policies. We further explore the potential for revenue insurance policies below.

Theoretical Demonstration

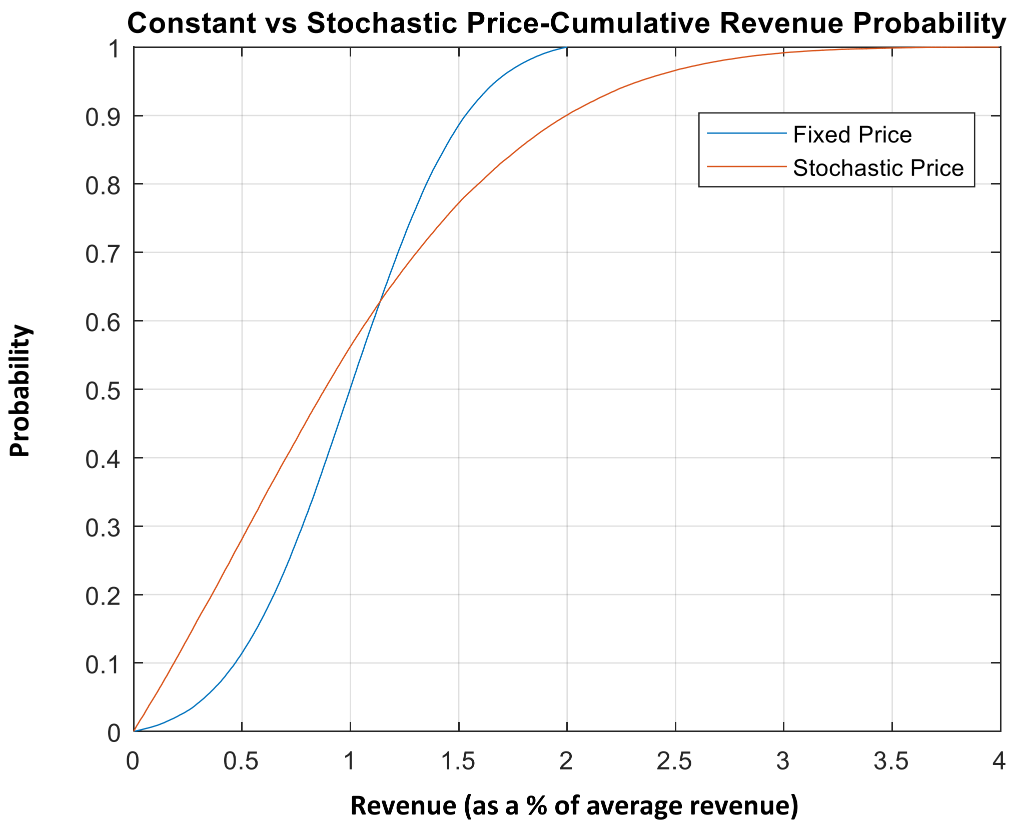
To illustrate the potential importance of insuring revenue, we develop a simple theoretical model of agricultural revenue with and without stochastic prices. We then consider area yield and area revenue insurance contracts and demonstrate how revenue contracts may improve upon area yield contracts. Lastly, we use our simulation to illustrate that revenue index insurance policies may improve demand for index insurance.

Consider a population of farmers that face yields $y_j = \Theta g$ where g is some production constant and Θ is a stochastic shock term, with a mean of 1, composed of idiosyncratic and covariant shocks $\Theta = \theta_i + \theta_c$. Farmers earn revenues of $R_j = \tilde{p} * y_j$ where $\tilde{p}$ represents a potentially stochastic price. Figure 2 presents a cumulative probability function for revenue for the case in which price is fixed at its mean, $\tilde{p} = \bar{p}$, and the case in which price varies independently of yields.[1]

[1] Note that we have made two simplifying assumptions in the model that we intend to relax in future work. First, we assume that there is only one price shock term. We could alternatively model the price shock as having a covariant

We find that price variability introduces additional risk into farmers' revenue, which implies that purely yield based index insurance policies may include greater basis risk than previously thought when we only consider basis risk in terms of yields.

Figure 2: Cumulative Revenue Probability With Stochastic Prices



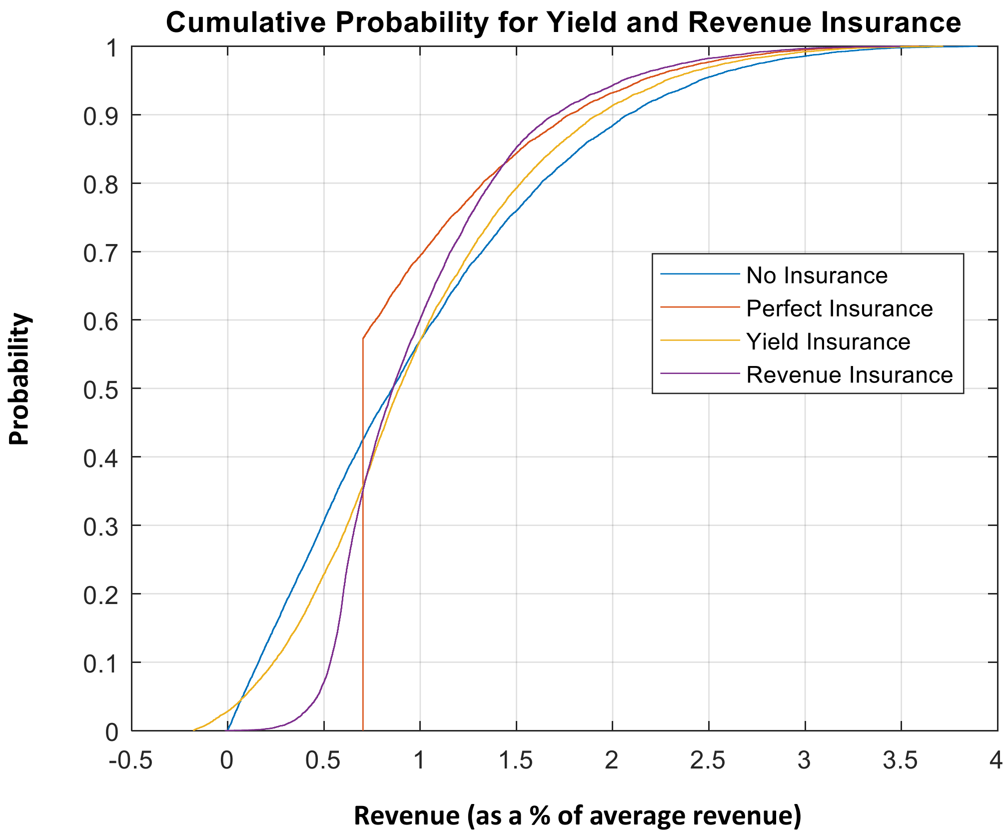
Here we present the CDF for simulated revenue data when assuming the price is fixed and assuming that price is stochastic.

We model two index insurance policies to explore the differences in basis risk that may be present when price varies. First, we model the yield based index insurance policy as a contract that pays out when the covariant shock drops below some trigger $\widehat{\theta_c}$, makes payouts of $(\widehat{\theta_c} - \theta_c) * g$, and charges a premium of π_y. Second, we model the revenue insurance as the combination of the yield contract and a price contract. The price contract pays out when the price drops below some trigger $\hat{p}$, makes payouts of $(\hat{p} - p) * \theta_c * g$, and charges a premium π_p. The revenue insurance contract then has a premium of $\pi_r = \pi_y + \pi_p$.

and idiosyncratic component as well. Second, we assume that the price shock is uncorrelated with yields; we will discuss this later when we present some initial empirical results.

In Figure 3, we present the CDF functions for revenue with stochastic prices without insurance, with perfect insurance, with yield insurance, and with revenue insurance. We find that revenue insurance out performs yield insurance with respect to the distribution of revenue. By insuring both yields and price, revenue insurance further approaches perfect insurance by reducing the probability of experiencing low revenue states and increasing the probability of experiencing high revenue states.

Figure 3: Cumulative Revenue Probability With Index Insurance Policies



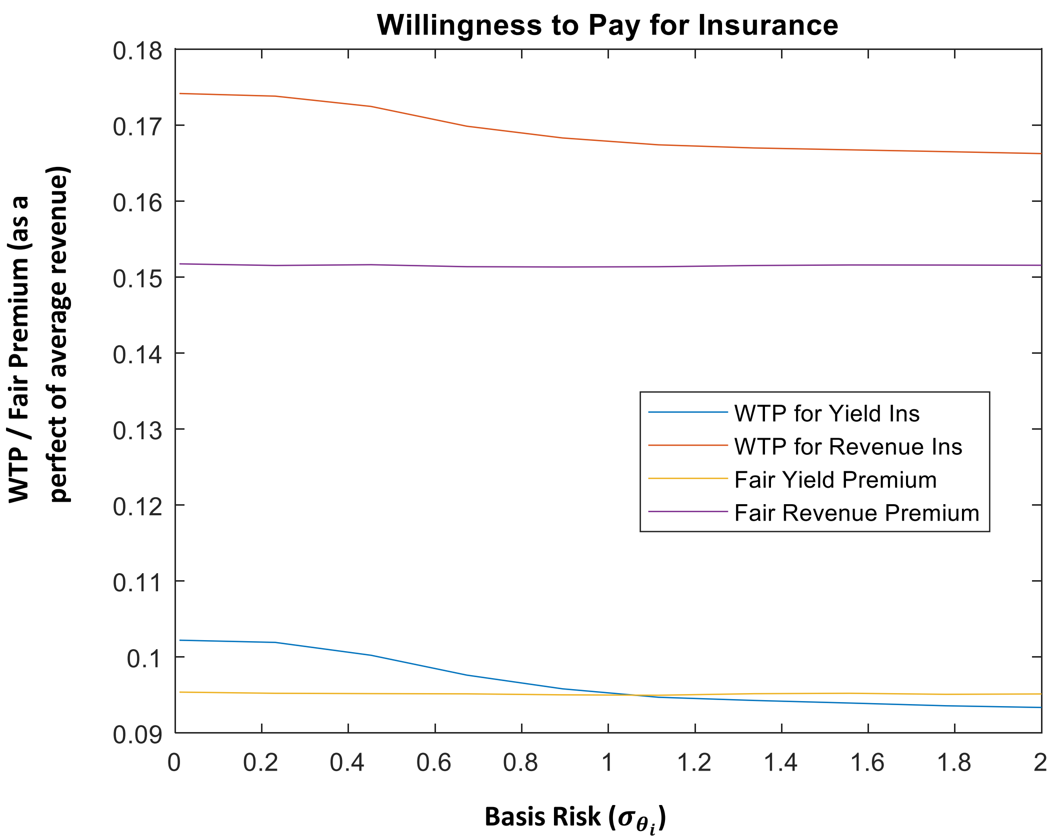
Here we present the CDFs for revenue with stochastic prices without insurance, with perfect insurance, with yield insurance, and with revenue insurance.

Having demonstrated the potential benefits of directly insuring revenue, rather than yields, we now may be concerned with the demand and value of revenue index insurance policies relative to yield insurance policies. Numerous studies have documented relatively low demand for index insurance policies (Miranda and Farrin 2012; Giné and Yang 2009; Cole et al. 2013) which is a rational response for risk averse agents when faced with significant basis risk (Clarke 2016). Therefore, designing index insurance policies that have sufficiently low basis risk to provide farmers with meaningful insurance is essential. To consider demand, we calculated the willingness to pay (WTP) for the revenue insurance policy and the yield insurance policy by solving

$U(R_I - \pi_j) = U(R_U)$ for π_j where $j \in \{r, y\}$ and R_I (R_U) represents revenue with (out) insurance.

In Figure 4, we plot WTP for revenue insurance and yield insurance as well as the fair premium for both versus the standard deviation of the idiosyncratic shock, which we use to indicate the extent of the basis risk. We find that for both contracts, WTP decreases as the variation in the idiosyncratic shock increases. However, we find that for the yield-based contract, WTP drops below the fair premium at a sufficiently high level of basis risk whereas the WTP remains consistently above the fair premium of revenue insurance. These simulations suggest that demand for revenue insurance will likely be higher than demand for yield insurance despite a higher cost.

Figure 4: WTP for Revenue vs Yield Insurance



Here we present the WTP for yield and revenue insurance alongside the fair premiums for each contract.

We further note that the above revenue insurance is potentially valuable to commercial farmers who are net producers. For these farmers, their primary concern is the agricultural income generated from their farming practices. However, we can also consider a subsistence farmer who is a net consumer. In this case, revenue insurance will actually be detrimental as such farmers are adversely affected by high market prices rather than low prices. For subsistence farmers we can imagine a consumption index insurance product that combines agricultural yields and prices yet the price trigger is set when prices rise above a given threshold. Therefore, the appropriate policy will be client dependent where revenue insurance is targeted to net producers and consumption insurance is targeted to net consumers. We intend to explore consumption insurance as well, which can be easily adapted from the design of the revenue index discussed above.

A Preliminary Look at the Data

We now ask if existing data on yields and prices from northern Ghana may shed light on the extent of price variations. Using farmer household level data collected between 2015 and 2017 in northern Ghana, we present district-level area yields and area prices in Table 1. We find that notable variation in prices do exist between regions and between districts. In Panel A of Table 2, we confirm this by conducting mean t-tests of maize prices between each pair of regions and find a significant difference between regions. Furthermore, in Panel B of Table 2, we use mean t-tests to confirm that significant variations in price exist across years as well. These results suggest that meaningful price variation does exist and a price index may be helpful to manage the crop price component of revenue variation.

Table 1: Yields and Prices by Region/District Averaged over 3 Years

Region	Yield	Price
Upper East	358.3 (227.7) kg/acre	1.14 (0.42) GHc/kg
Bawku Municipal	417.3 (231.1)	0.98 (0.28)
Bawku West	469.6 (247.6)	1.2 (0.27)
Binduri	309.5 (211.9)	1.01 (0.27)
Bolgatanga Municipal	374.8 (229.8)	1.1 (0.18)
Bongo	318.3 (232.5)	1.2 (0.28)
Builsa North	185.2 (115.9)	1.19 (0.28)
Builda South	165.6 (64)	1.18 (0.55)
Garu Tempane	338.9 (217.5)	1.18 (0.53)
Kasena Nankana East	349.4 (187.2)	1.17 (0.32)
Kasena Nankana West	261.3 (153.3)	1.1 (0.22)
Upper West	349.1 (220.1) kg/acre	1.08 (0.25) GHc/kg
Jarapa	306.9 (174.6)	1.2 (0.24)
Lambussie Karnie	339.6 (207.4)	1.1 (0.19)
Lawra	168.7 (82.6)	1.2 (0.08)
Nandom	316.5 (182.8)	1.12 (0.12)
Sissala East	643.3 (272.9)	0.87 (0.17)
Sissala West	556.5 (280.8)	0.69 (0.26)
Northern	325.5 (198.1) kg/acre	0.92 (0.29) GHc/kg
Bonkpirigu Yongyong	386 (191.6)	0.99 (0.17)
Chereponi	297.7 (170)	0.99 (0.21)
Gushegu	321.4 (185.8)	0.78 (0.14)
Karaga	438.8 (275.4)	0.86 (0.12)
Mamprugumogduri	372.1 (212.1)	0.83 (0.15)
Mamprusi East	348.3 (230.5)	0.8 (0.13)
Mamprusi West	324.3 (207.6)	0.89 (0.44)
Saboba	285.8 (176.5)	1.03 (0.18)

Table 2: Mean t-test comparisons for maize prices across regions.

Panel A: Price Variation Across Regions			
Mean Price Northern Region	Mean Price Upper West	Mean Price Upper East	Difference
0.92	1.08		0.16***
	1.08	1.14	0.055**
0.92		1.14	0.22***
Panel B: Price Variation Across Years			
Mean Price 2015	Mean Price 2016	Mean Price 2017	Difference
0.97	1.15		0.18***
	1.15	1.02	0.13**
0.97		1.02	0.06***

Notes: p<0.1 *, p<0.05 **, p<0.01 ***

In our model, we assumed that price and yields varied independently. However, in markets that are, to some extent, isolated from national or international markets, area yields and area prices may be negatively correlated. If they are indeed negatively correlated, these price variations may actually serve as a form of insurance, compensating farmers for yield shocks with increased prices. Such a negative correlation would further reduce the benefit of a yield-based insurance policy and emphasize the need for a policy that combines yield and price indices. To investigate this, we generated community-year average maize yields and prices and regressed prices on yields as well as region fixed effects; we present our results in Table 3. We find a negative relationship between yields and prices significant at the 1% level which suggests that there is a negative correlation between yields and prices in these markets. This implicit insurance via price variations may provide an additional reason to explain relatively low demand for index insurance policies to date and illustrates the importance of capturing price variation in future index insurance policies. However, the magnitude of the relationship is only 0.02 Ghana cedis, which is somewhat small which may suggest that this price insurance mechanism is only provides farmers with a limited amount of implicit insurance.

Table 3: Correlation between Yield and Price

Variables	Maize Price per KG
Maize Yield (100KG)	-0.02***
Constant	0.98***
Regional Fixed Effects	YES
R^2	0.2
Clusters	564
N	2,324

Notes: p<0.1 *, p<0.05 **, p<0.01 ***; Maize yield data is averaged at the year and community level; Clustered robust standard errors at community-year level.

Based on our initial theoretical and empirical considerations, we believe that crop price variation may be an essential component of farmer income risk. Therefore, to create index insurance policies that provide critical insurance coverage for farmers and minimize basis risk, price variation should be considered.

IV. Project Activities

Improved Area Yield Index

We intend to partner with the remote sensing research team at the University of California Davis to develop area yield indices based on remote sensing data. We will calibrate these indices using household data from the Ohio State University based research team lead by Mario Miranda and the Northwestern based research team lead by Chris Udry. Furthermore, we will carefully calibrate our yield indices to optimize insurance zone sizes and explore other contract features such as second stage audits to minimize basis risk.

Revenue Index Development and Insurance Products

Our second project activity will be to develop basis risk minimizing area revenue indices and corresponding index insurance products. We will design our revenue index insurance policies using three sources of data. First, household level data from the Ohio State University based research team lead by Mario Miranda, the Northwestern based research team lead by Chris Udry, and most importantly, market prices from Tamale, Wa, and Yendi in northern Ghana.

Piloting Innovative Index Insurance Policies

Our third project activity is to work with the Ghana Agricultural Insurance Programme (GAIP) to pilot our newly developed index insurance policies. GAIP remains the exclusive private sector provider of agricultural index insurance policies in Ghana. At present GAIP offers rainfall based index insurance policies to individual farmers, cooperatives, and banks as well as agricultural loan portfolio insurance for banks. However, their products remain open to considerable improvement in design and marketing. We propose to use your improved indices and insurance contracts to improve the products that GAIP offers and therefore improve GAIP's ability to offer effective risk management products in Ghana's agricultural sector. We propose that throughout the development of new products, we will work closely with GAIP to develop products that they believe will improve upon their current products and will be effectively marketable. Furthermore, in the final year of our work, we will work with GAIP to market and implement our new products and will explore means of rigorously evaluating demand for these products.

V. Outputs

Our proposed project will produce a number of tangible outputs that will have direct positive impact on the lives of smallholder farmers, the index insurance industry in Ghana, and the academic community's further research on smallholder risk management. We will produce the following four outputs:

1. At least two new index insurance products developed.
2. One technical report detailing the new products, potential for impact, and policy recommendations.
3. One Policy Brief.
4. Two academic publications.

VI. Personnel

Institutional Partners

1. Ghana Agricultural Insurance Programme (GAIP)

Technical Advisory Team

1. Jon Einar Flatnes
2. Mario J. Miranda
3. Michael Carter

Satellite Measurement and Yield Index Design

1. University of California Davis Team

Project Management and Data Collection

1. Acheampong Consultants – Accra

VII. Budget

Below we provide the detailed proposed budget for our work. The total expense is $124,989 with $78,609 allocated for direct costs and $46,379 for indirect costs. An important note in this budget is the yield index line item, which provides the funds allocated for hiring a remote sensing team to work with the remote sensing data and to help produce the insurance index. The current plan is to hire the remote sensing team located at the University of California at Davis. However, we have not yet finalized an arrangement with them. If we are able to contract with them, we request that the funds for this work be transfer directly to them, rather than transferred initially to Catholic University of America. However, if we contract with a different remote sensing group, we request that the funds be transferred here.

Item	**Description**	**Cost**
Field Activities		
Yield Index Development	Hiring remote sensing team to design yield index.	$25,000
Data Collection	Hiring a private data collection agency	$16,600
Travel Expenses		
International Travel	Field Visits for PI, Graduate Student, and other key personnel (three trips of two people each trip)	$15,840
Compensation		
PI Salary	One PI salary for two summers	$9,059
PI Fringe Benefits		$2,151
GRA Stipend	Compensation for one graduate student for two summers	$6,000
GRA Fringe Benefits		$459
Other Expenses		
Material Expenses	Materials such as printing, survey materials, etc.	$3,500
Total Direct Costs		$78,609
Indirect Costs	Catholic University Indirect Costs	$46,379
Total		**$124,989**

VIII. References

Agriculture in Ghana: Facts and figures (2012). Ghana Ministry of Food and Agriculture. Available at: http://agrihomegh.com/wpcontent/uploads/2017/01/Mofafactsandfigures2012.pdf (last accessed 07 June 2018).

Cai, H., Chen, Y., Fang, H., and Zhou, L. 'The Effect of Microinsurance on Economic Activities: Evidence from a Randomized Field Experiment', *The Review of Economics and Statistics,* Vol. 97(2), (2015) pp. 287-300.

Carter, M. Innovations for Managing Basis Risk under Index Insurance for Small Farm Agriculture. Foundation Pour Les Études et Recherches sur Le Développement International Policy Brief (41) 2011. Available at: http://www.ferdi.fr/sites/www.ferdi.fr/files/publication/fichiers/B41.pdf (last accessed 17 June 2018).

Carter, M., Elabed, G. and Serfilippi, E. 'Behavioral economic insights on index insurance design', *Agricultural Finance Review,* Vol. 75(1), (2015) pp. 8–18.

Carter, M.R., Cheng, L. and Sarris, A. 'Where and how index insurance can boost the adoption of improved agricultural technologies', *Journal of Development Economics,* Vol. 118, (2016) pp. 59–71.

Clarke, D. 'A Theory of Rational Demand for Index Insurance', *American Economic Journal: Microeconomics,* Vol.8(1), (2016) pp. 283-306.

Clarke, D., Mahul, O., Rao, K., and Verma, N. *Weather Based Crop Insurance in India*, Policy Research Working Paper 5985 (The World Bank: 2012).

Cole, S., Giné, X., Tobacman, J., Townsend, R., Topalova, P. and Vickery, J. 'Barriers to Household Risk Management: Evidence from India', *American economic journal: Applied economics,* Vol. 5(1), (2013) pp. 104–135.

Elabed, G., and Carter, M. R. *Ex-ante Impacts of Agricultural Insurance: Evidence from a Field Experiment in Mali,* Working Paper (University of California Davis: 2015).

The Economic Lives of Smallholder Farmers: An Analysis Based on Household Data from Nine

Countries. Food and Agricultural Organization. 2015. Available at: http://www.fao.org/3/a-i5251e.pdf (last accessed 17 July 2018).

Farrin, K., and Miranda, M. J. ‘A Heterogeneous Agent Model of Credit-linked Index Insurance and Farm Technology Adoption’, *Journal of Develepont Economics,* Vol. 116(202), (2015) pp. 199-211.

Flatnes, J. E., and Carter, M. R. *Fail-safe index insurance without the cost: a satellite based conditional audit approach.* Working Paper (The Ohio State University, 2015).

Ghana Living Standards Survey Round 6: Main Report. Ghana Statistical Service. 2014. Available at: http://www.statsghana.gov.gh/docfiles/glss6/GLSS6_Main%20Report.pdf (last accessed 07 June 2018).

Gine, X. and Yang, D. ‘Insurance, credit, and technology adoption: Field experimental evidence from Malawi’, *Journal of Development Economics,* Vol. 80(2009):1-11.

Karlan, D., Osei, R., Osei-akoto, I. and Udry. C. 'Agricultural Decions After Relaxing Credit and Risk Constraints', *Quarterly Journal of Economics,* Vol. 129(2), (2014) pp. 597–652.

Miranda, M.J. and Farrin, K. 'Index Insurance for Developing Countries', *Applied Economic Perspectives and Policy,* Vol. 34(3), (2012) pp. 391–427.

Mishra, K., Gallenstein, R., Sam, A.G., Miranda, M.J., Toledo, P., and Mulangu, F. *You are Approved! Insured Loans Improve Credit Access and Technology Adoption of Ghanaian Farmers*, Working Paper (The Ohio State University: 2018).

Mobarak, A. M., and Rosenzweig, M. *Selling formal insurance to the informally insured,* Working Paper (Economic Growth Center, No. 1007: 2012).