Agricultural Index Insurance: An Optimization Approach

1 Introduction

Farmers, especially farmers in developing countries, are constantly exposed to a variety of risks. Due to financial market failures, rural farmers in developing countries rarely have access to the risk management tools used by farmers in wealthier countries to manage risk. As a result, when poor farmers do experience a negative shock, they are often forced to rely on coping strategies that hurt their long-term welfare. Agricultural insurance is, even in the best circumstances, a hard problem. Many of the features one would want (independent units, uncorrelated risk, etc) are missing in this context. When considering insurance in developing countries, the problem becomes even harder because of verification costs. Agriculture in developing countries is often characterized by many small farmers spread out over hard to reach regions. This makes verification in these contexts prohibitively costly. Additionally, the presence of correlated risks makes insurance more expensive because it makes large payouts more likely. Intuitively, if one farmer is affected by a drought, it is likely that other farmers were also affected. If large payouts are more likely, the insurer must have larger reserves in order to maintain solvency. The lack of insurance also affects access to credit in these settings. Financial institutions are usually hesitant to offer loans in these contexts due to the large covariate risk. This lack of access to credit can prevent farmers from adopting profitable technologies that require upfront investment. Access to insurance could potentially lead to expanded access to credit and facilitate technological adoption.

Researchers developed index insurance as a less costly way to offer insurance in developing countries. In index insurance, an index (or statistic) is created using easily observable quantities, and it is used to determine whether the insured party suffered an adverse event. In the past, indices have been constructed using rainfall, weather, and satellite images. If the index falls below a pre-determined threshold, the insurance company automatically issues out payments to the insured. Even though index insurance has proved to be a less costly way of providing insurance for small farmers, it has been difficult to scale up.

The goal of this project is to improve the efficiency of index insurance through better contract design. We develop a method to design the contracts of all insured zones simultanesouly. Our method takes into account the correlation of losses between zones when designing the contracts, allowing for better risk management.

2 Data

Thailand's Department of Agricultural Extension (DOAE) has an extensive dataset of plot level information for farmers in Thailand. This data incldues each plot's geographical boundaries as well as information on rice planting activities. Loss data is available from the Government Disaster Relief Program, which provides administrative records of disaster relief payments for rice production loss caused by natural disasters. This dataset includes the rice variety planted, the planting date, the harvest date, the total loss, and the date in which the disaster occurred. It has roughly 22 million observations spanning from 2015-2022. This dataset's coverage is nationwide. Due to the sensitive nature of the data, it can only be accessed from a secure computer located in the Bank of Thailand's facilities. It is worth highlighting that this is a highly unique dataset for the context of index insurance. One of the difficulties in conducting research in index insurance is the lack of farmer level yield data, especially in lower or middle income countries. One of the most exciting aspect of this project is that it could inform investment decisions for the governments of similar countries.

3 Method

Index insurance generally involves an easily observable signal, θ, that is used to predict the loss, $\hat{\ell}(\theta)$, of some agricultural product. For example, θ could be rainfall, and $\hat{\ell}(\theta)$ could be livestock mortality. Index insurance is generally used in contexts where it is too costly to observe the true loss, $\ell(\theta)$, so it is based on a predicted loss, $\hat{\ell(\theta)}$ instead. Index insurance contracts normally have the following form:

$$I(\theta) = \; I(\hat{l}(\theta)) \triangleq \; \min\left\{\max\left\{0, a\hat{\ell}(\theta) + b\right\}, 1\right\}, \tag{1}$$

where a, b are the contract parameters. Without loss of generality, the maximum payout is scaled to be one here. We also use $I(\theta)$ instead of $I(\hat{\ell}(\theta))$ for ease of notation. The premium a farmer pays for an insurance contract $I(\theta)$ is:

$$\pi(I(\theta)) \triangleq \; \mathbb{E}[I(\theta)] + c_\kappa K(I(\theta)). \tag{2}$$

Here, the premium $\pi(I(\theta))$ is the expected payout plus costs of capital. $K(I(\theta))$ is a function of $I(\theta)$ that represents the amount of capital required to insure the contract, and it is usually set by regulators and meant to ensure that insurers have enough capital to fulfill their contractual obligations with high probability. Intuitively, when $\mathbb{E}[I(\theta)]$ is the same for two different contracts, if one of them is riskier for the insurer than the other, then the insurer will have to sell it at a higher price to make the same profit. The additional term $c_\kappa K(I(\theta))$ captures this additional cost of risk. c_κ is the cost of holding capital. The model we developed for designing insurance contracts for multiple zones is:

$$
\begin{aligned}
\max_{a,b,K,\pi} \quad & \mathbb{E}\left[\sum_z U\left(w_0 - \ell_z - \pi_z + I_z(\theta_z)\right)\right] && (3)\\
\text{s.t.} \quad & \pi_z = \mathbb{E}\left[\overline{I_z(\theta_z)}\right] + \frac{c_\kappa}{\sum_z s_z}\left[\mathsf{CVaR}_{1-\epsilon_K}\left(\sum_z s_z \overline{I_z(\theta_z)}\right) - \mathbb{E}\left[\sum_{z'} s_{z'} \underline{I_{z'}(\theta_{z'})}\right]\right] && (4)\\
& \overline{I_z(\theta_z)} = \max\left\{0, a_z\hat{\ell}_z(\theta_z) + b_z\right\}\\
& \underline{I_z(\theta_z)} = \min\left\{a_z\hat{\ell}_z(\theta_z) + b_z, 1\right\}\\
& \pi_z \leq \overline{\pi_z}.
\end{aligned}
$$

Here, our objective is to maximize overall farmer utility. Here, w_0 is initial wealth, ℓ_z denotes the loss for a farmer in zone z, π_z is the premium for zone z, and $I_z(\theta_z)$ is the payout for zone z. The first constraint specifies the definition of the premium. Here, the cost of capital is defined as $K(I(\theta)) \triangleq \mathsf{CVaR}_{1-\epsilon_K}\left(\sum_z s_z \overline{I_z(\theta_z)}\right) - \mathbb{E}\left[\sum_{z'} s_{z'} \underline{I_{z'}(\theta_{z'})}\right]$ as described in Mapfumo, Groenendaal, and Dugger (2017). The next two constraints specify the piecewise linear structure of the contract, and the last constraint limits the size of the premium.

4 Objectives

We have evaluated our method using both observational and synthetic data, and we found that our method outperformed the baseline. The Bank of Thailand is working on designing the country's index insurance program. I have been collaborating with them over the last year to improve different aspects of the program. The design of an index insurance program generally consists of three steps. The first step is to design a model to predict loss. The second step is to design contracts that map predicted losses to payouts. The last step is to price these contracts. In my previous visit, I worked on improving the prediction model used in the insurance program. The next step in the program design is the contract design. The objective of this trip is two-fold. First, their data will provide us an opportunity to better evaluate our method. We further hope to improve the method using input from the team at the Bank of Thailand, and from interviews and focus group discussions with farmers. Second, if our method proves effective, we could use it to inform the contract design of the country's index insurance program.