CREATING SUSTAINABLE AGRICULTURE INDEX BASED INSURANCE SCHEMES: CATASTROPHIC RISK ALLOCATION IN A CASE STUDY FROM COCHABAMBA, BOLVIA

(VERY PRELIMINARY VERSION)

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Abstract

Index based insurance schemes for agriculture in the developing world are struggling to fulfill the initial expectations created. Aside from structural obstacles, two market related constraints hinder their expansion to some of the poorest regions: i) high premiums associated to the costs of catastrophic events; and ii) low willingness to pay on behalf of insurance schemes beneficiaries. In this document a two step solution to create public – private partnerships to deliver index insurance to poor regions is introduced. The approach consists on, first, redefining the levels of catastrophic risk so that only expected loss is covered by commercial insurance; and, secondly, allocating the remaining exceedence curve among different financial instruments for catastrophic risk, as proposed by Mahul and Gurenko (2006). Results from pilot design in Cochabamba, Bolivia, are also presented.

JEL Codes: Q14, Q18, G22, G23, G28.

1. Introduction.

Index microinsurance products have shown their potential to help smallholders to escape from poverty traps in the developing world (Giné, 2009; Karland and Morduch, 2009). However they have not been able to scale up as it was initially proposed (Burke, et al, 2010; Skees, et al, 2009). Aside from structural problems, such as insufficient meteorological infrastructure coverage, two market related elements hinder their development and sustainability: low willingness to pay on behalf of smallholders and expensive policies derived from poor risk management (Global AgriRisk, 2010).

The price of an insurance policy is basically the sum of the risk cost, the administrative and a catastrophic load. Given the absence of abundant catastrophic type of events to robustly predict their occurrences, index insurance schemes usually rely on simulations based on historical data. However, simulations generally entail higher levels of uncertainty given the limited number of observations and the quality of such data (Global AgriRisk, 2011). Furthermore, climate change, by changing the frequency and intensity of extreme events undermines the usefulness of historical data. All these elements together add up to larger premiums for catastrophic risk to be charged by reinsurance companies, which are eventually transferred to insurance beneficiaries (Murphy, et al, 2007; Skees, et al, 2009).

The relative high costs of providing the services contrasts with the low willingness to pay for these products despite their potential benefits. Producers’ willingness to pay for such as products is generally small. International figures suggest that prices should lie somewhere between 5% an 10% of the insured value (Burke, et al, 2010; Giné, et al, 2009; Heenkenda, 2010). This situation can be explained by several reasons. First, smallholders may have difficulties to understand complex concepts such as expected losses, trigger payments, among other (Patt, et al, 2009). Secondly, their incomes are low relative to the costs of the insurance policy, and unless insurance schemes pay on regular bases, rural smallholders may not find beneficial to buy the policies.
Because of this reality, in most of the experiences with index based insurance, government involvement has been crucial to foster the development of insurance markets, as well as creating the conditions to include the private sector. For instance, 16 out of 19 experiences of agriculture insurance schemes, reviewed by Arias and Itorruiz (2010), included substantial government involvement. Furthermore, there are several arguments in favor of such type of interventions.

States can have a subsidiary role to enhance agricultural microinsurance market development based. In most of the developing world, meteorological infrastructure is scarcely distributed, which makes difficult to estimate accurate values for the policies to be commercialized among interested rural smallholders (Global AgriRisk, 2010). Thus, climatic infrastructure becomes a public good and government intervention might be justified in this regard. Secondly, subsidies can be justified on the grounds of social policy. Generally, the most vulnerable to climate hazards are poor rural producers; finding financial instruments to support them to escape from poverty is becoming a policy priority in several countries of the developing world.

However, the opportunity cost of public funds can become a paramount piece of analysis, particularly when budget constraints are relevant. Establishing subsidies for premiums can be costly and the program can be halted during tight financial times for governments. In this regard, finding financial instruments that may help to alleviate this burden becomes important.

Commercial insurance alone schemes may not succeed without public intervention as was mentioned above. However reinsurance, combined with contingent credit and government reserves schemes combined can become an alternative that creates sort of a public private partnership to provide the service.

The framework presented below, based on the theoretical contributions of Gurenko and Mahul (2006), and Andersen et al (2010), may emerge as an alternative that allows for both privately driven, commercially sustainable insurance schemes, along with cost – optimized public subsidy scheme. Specifically, the proposal consist of two steps: i) using a payment scheme, common in this type of insurance, we propose to redefine the levels of catastrophic risk in a way that satisfies demand side and supply side restrictions; and ii) redefined the levels of catastrophe, optimally allocate the costs as proposed by Gurenko and Mahul.

The paper is structured as follows. Section 2 derives the theoretical framework for risk allocation among financial instruments, given the constraints imposed by demand’s willingness to pay. Section 3 presents the results of a case study for a pilot index based insurance scheme in Cochabamba, Bolivia. Section 4 presents the results of the pilot program under the framework here described. Finally, section 5 concludes with some policy implications.

The basic premise under which this proposal is built is that to make an insurance scheme sustainable, it is necessary to address the problems of consumers’ small willingness to pay as well as offering a solution to the costly problem of risk allocation simultaneously. Particularly, we argue that the cost of risk (the expected loss) should be absorbed by the insurance beneficiaries, obtaining from them their highest willingness to pay. The rest of the risk should then be regarded as catastrophic, and allocated among different financial instruments designed for the purpose. In this latter stage is where government intervention becomes crucial.

Index based insurance schemes are constructed upon the estimation of two elements: a consequential, due to a climatic event, loss assessment; and the probability associated to such a climatic event. Conditional on the type of insurance and the availability of historical climate and crop yield data, different methodologies were utilized throughout the world to estimate both set of parameters (Global AgrRisk, 2010 and 2011). Equation (1) defines the price of the insurance policy:

\[
\text{Price}_{\text{policy}} = (1 + \alpha) \cdot EAL + \theta \cdot MLL + \text{Administrative_expenses}
\]

The price of a premium is composed of three elements. The first one represents the cost of risk, defined by the Expected Adjusted\(^4\) Loss (EAL); the coefficient \(\alpha\) represents the percentage value of the EAL that is required for insurance the regulators plus insurance shareholders’ appetite for benefits.

The second term is the cost of catastrophic risk. It is composed out of two elements. The Maximum Likelihood Loss (MLL), defined as the Value at Risk\(^5\) beyond a certain threshold, usually 100 o 150 years. The second \(\theta\), is the percentage value of such losses that needs to be annually covered by the insurer. It might be established by regulators, and also represents the cost that reinsurance companies charge for the risk transfer of catastrophic losses derived from less frequent events.

Finally, the price includes the administrative costs associated to delivering the service in rural settings.

\(\text{a. Redefining Catastrophic Levels.}\)

Among demand side restrictions, the one that impedes the most the development index insurance is low willingness to pay. International figures suggest total expenditure on the lie on the range between 5% and 10% of the insured value (Burke, et al, 2010; Heenkenda, 2010).

Population in some regions may not be able to reach this minimal threshold. Climate vulnerable locations where natural hazards may lead to close to starvation states of the world, where climate may lead to frequent losses, or that a large share of the family income stems from agriculture are somehow prevalent in several regions of the developing world.

\(^4\) Adjusted for the number of missing values and the information available on a given meteorological station. See xxxx for further details.

\(^5\) Value at Risk: average value of the losses beyond a given threshold. Represents the expected losses caused by events that occur once in more than one hundred years.
This restriction can be included in the cost of risk. Assuming that data on the willingness to pay (WTP) among target population is available, the first element of equation (1) can be modified to satisfy the constraint that willingness to pay imposes.

This is done taking advantage of an index commonly used in agriculture insurance schemes. In excess rainfall or drought insurance schemes, \( X \) represents a random level of precipitation, \( X_t \) the threshold level or rainfall below (above) which payments are triggered, and \( X_{cat} \) is the level of precipitation above (below) regarded as catastrophic; i.e. rainfall such that only 10% of the yield can be harvested at the end of the season. From now on, only the drought case will be considered, however it is straightforward to analyze the case when flood is the natural hazard to be covered; results on Section 3 and 4 include an excess of rainfall scenario.

\[
Loss = g(X) \cdot \lambda(X) \tag{2}
\]

Thus the loss function \( Loss(\cdot) \) for a given insured value \( Value \) can be described by the product of two functions, as described by (2). A consequential losses assessment, \( g(X) \), that depends on the level observed for a random climatic variable, \( X \) (rainfall, for instance). This function ought to be increasing in \( X \): \( g'(X) > 0 \) and \( g''(X) > 0 \). The particular functional form of \( g(X) \) will come from either relating historical data on climate and output were series of data available; or by using crop simulation models, when historical information on yields does not exist. In the next section a description of how this was estimated in Bolivia is present (see further details in Nogales y Córdova, 2013).

The second term is the probability density function (pdf) for a particular realization of \( X \) taking place during the relevant phonological stage. Usually, this pdf is empirically retrieved from historical weather data. For now, let the rainfall process during the timeframe of interest be represented by the distribution function \( \lambda(x) \), with cumulative distribution \( F(x) \).

Losses are usually defined over a set of index values. As long as the weather index is above a certain level (in the case of drought insurance), no payment is done to producers. On the contrary, if rainfall levels lie below a lower bound, called catastrophic, all the insured value shall be paid to producers.

Between this trigger level and a lower bound counterpart, a catastrophic level, payments are made using sliding scale mechanisms, so they reflect the losses actually experienced. This is called a tick. Several types of ticks were used in weather insurance experiences. One that will be useful is to define the sliding scale as the percentage of consequential losses with respect to the trigger level of output, defined by \( \delta = \frac{[Y(x) - Y_T]}{Y_T} \), such that \( \delta \in [-1,0] \). The parameter delta is bounded, as producers cannot experience losses larger than their entire harvest. The expected loss for a given realization of rainfall, \( x \), is given by the set of equations described below.

\[
\begin{align*}
Loss(\cdot) = & \begin{cases} 
0 & \text{if } x > X_T \\
Value \cdot \frac{[Y(x) - Y_T]}{Y_T} \cdot \lambda(x) & \text{if } X_{cat} < x \leq X_T \\
Value \cdot \lambda(x) & \text{if } x \leq X_{cat}
\end{cases}
\end{align*}
\]
In order to allocate the risk among different parties, it is proposed here that the loss function in the range $X_{\text{cat}} < x \leq X_T$ be considered as the cost of risk, or the first element in equation (1). This share of the total premium, defined by the absolute number of delta, would be financed via the contributions of the beneficiaries and carried out under commercial principles. Either a private or a public firm would have to deliver the service at a given cost and obtain a return for the service.

$$(1 + \alpha) \cdot \int \text{Value} \cdot \frac{[Y(x) - Y_T]}{Y_T} \cdot \lambda(x) \, dx$$

Thus, the net WTP, discounting the administrative expenditures, will be given by equation (3). Assuming that the WTP is known, it is possible to calculate a value for a new level of catastrophic risk, $X_{\text{cat}^*}$, that satisfies the demand constrain. Therefore: $X_{\text{cat}^*}$ will now be new level of catastrophe such that all the cost of risk up until that point is actuarially financed by beneficiaries; the probability associated to such a level of will be given by $\lambda(x_{\text{cat}})$.

$$\text{Price} = \left[\text{WTP} - \text{Adm}_{\text{expenses}}\right]/(1 + \alpha) \geq \int \text{Value} \cdot \frac{[Y(x_{\text{cat}^*}) - Y_T]}{Y_T} \cdot \lambda(x) \, \lambda(X)dX \quad (3)$$

Under this mechanism, a commercial, privately driven, insurance scheme may be put in place, taking care of the losses up to a level where demand is capable to pay for. Smaller losses, below the trigger value, $X_T$, will be covered by auto-insurance; while larger losses caused by drought (flood) precipitation levels below (above) $X_{\text{cat}}$ will regarded as catastrophic. This corresponds to the second term in equation (1), MLL. A graphical representation of the process can be found on Figure 1. The new level of catastrophe, $X_{\text{cat}^*}$, would lie to the right of the originally defined $X_{\text{cat}}$.

Figure 1. Risk Transfer Under an Index Based Insurance Scheme

b. Efficient Allocation of Catastrophic Costs.
As was previously mentioned, the second term of equation (1), MLL, is commonly estimated using Value at Risk (VaR) techniques for once in a hundred years, for instance. The newly defined catastrophic level changes the VaR to be considered. Given that the probabilities of the original and adjusted for WTP catastrophic levels is given by \( \lambda(X_{cat}) = 1/t < \lambda(X_{cat}^*) = 1/t^* \), this entails that the VaR under the newly defined catastrophic level will need to be assessed for events whose probabilities of occurrence are smaller than \( 1/t^* \).

Drought and flood losses under insurance schemes will typically behave as described by the exceedance curve, represented in Figure 2. Consequential losses will increase in the range defined by probabilities \( 1/t^* \) and \( 1/t^{\star\star} \) (associated to a level of rainfall \( X^{\star\star} \)). Beyond this point, loses no longer grow bigger (ie. yield is bounded to positive numbers). Equation (4) defines the catastrophic loss function that satisfies the conditions required by Mahul and Gurenko (2006).

\[
MLL = \begin{cases} 
\int \frac{Y(x) - Y_{cat^*}}{Y_{cat^*}} \cdot \lambda(x)dx \quad & \text{if } x^{\star\star} \leq x < x_{cat^*} \\
\text{Value} \cdot [F(x^{\star\star})] \quad & \text{if } x < x^{\star\star}
\end{cases}
\]  

(4)

**Figure 2. Exceedance Curve for a Typical Index Insurance**

This is where the Gurenko and Mahul (2006) framework becomes relevant. These authors find different cost functions for three different financial alternatives. The first, and perhaps the most traditional one, is to transfer this risk to reinsurance markets. The second alternative is to access to credit contingent facilities provided by the World Bank; the third one is to use reserve funds. To optimally allocate the catastrophic costs between the available options requires solving a cost minimizing problem, defined by the set of cost equations for each of the three alternatives (5):

\[
\begin{align*}
\text{Reinsurance} &= \theta \cdot MLL \\
\text{Reserves} &= \frac{l_s - s_g}{1 + r} \cdot MLL \\
\text{Contingent Debt} &= \left[ l_f + \left( \frac{1 + l_r}{1 + r} \right)^m - 1 \right] MLL - l_c
\end{align*}
\]

(5.1)  (5.2)  (5.3)

Where MLL is the maximum likelihood loss for a VaR defined by \( \lambda(X_{cat}^*) = 1/t^* \), \( \theta \) is the percentage value of such losses that needs to be annually covered by the insurer. \( l_s \) represents
the social discount rate for public funds, $s_g$ is the risk free interest rate, and $r$ accounts for the current market interest rate. Regarding Contingent Debt, the terms of the credit are $l$, interest rate, chargeable upon disbursement of the loan, with a maturity of $m$ years; a commitment fee of $l_c$ charged on the committed loan is paid every year for maintaining the credit line in a stand-by status. Finally, a front-end fee of $l_f$ is charged on the disbursed amount of capital.

The final outcome is the allocation of risk in different layers of exposure. For every layer of risk, a cost minimization algorithm is implemented.

3. Case Study in Cochabamba, Bolivia.

a. Bolivian Agriculture Insurance Market and the Pilot Design

Agriculture insurance products tend to have low penetration rates in Latin America. Arias an Itorruiz (2010) do an excellent analysis on the situation of insurance markets in the region. Bolivia is well below Latin-American these numbers (See Nogales, Córdova and García, 2012 for a review of the Bolivian market).

However, there is government good will to expand the usage of insurance product. A law was issued in 2011 aimed at enhancing the markets. At the same time, the National Institute for the Agrarian Insurance (INSA) was created to carry out the coordination for the design and implementation of a subsidized program for catastrophic insurance, called Pachamama$^6$ (SAMEP)$^7$. SAMEP was released in 2012. The program delivers catastrophic assistance for six different crops in the 70 poorest municipalities in Bolivia.

The initiative is certainly good and can be justified on social justice grounds; however, it suffers from lack of design to effectively expand its coverage. Most of the insurance policies are subsidized up to a 90% from national and regional governments. A fixed amount of monetary payoff in case of catastrophe was defined, paying little attention to regional and crop differences. Finally, SAMEP has a tight budget; last year government transferred 4 million dollars to support the program.

This feature inhibits its development to other regions where agriculture insurance may improve the wellbeing of the population. Bolivia is still characterized by having a large population that is highly dependent on agriculture. More than 30% of the households make their incomes out of agriculture activities. However it only contributes less than 9% of the Bolivian GDP, and the largest share of poverty remains being rural.

INSA planned to offer the product commercially. Actually, a call to procure the service to private providers took place during 2012 and 2012. No proposal was finally awarded. Now INSA will likely take care of the program.

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$^6$ Mother Earth in quechua.

$^7$ In Spanish: Seguro Agrícola de los 70 Municipios Más Pobres Pachamama.
Is in this context that Universidad Privada Boliviana (UPB) and INSA obtained a research grant from the Interamerican Development Bank (IDB) to design a pilot index based insurance policy for rural producers. The municipality of Anzaldo, located in the Department of Cochabamba, in a central – west region of the country, was selected.

This town was selected for several reasons. First, it is considered among the 70 poorest municipalities of the country. Second, one of the longest historical series of daily climate data is available for an important share of Anzaldo’s territory. Third, wheat and potato get the lion’s share of regional production, both products considered as strategic under the SAMEP program.

In this regard, the project offers a unique opportunity to test for alternative product designs with the hope to eventually replicate at a national scale some of the successful lessons obtained during this research timeframe.

b. Data and Analysis.

As described above, two main pieces of information need to be generated in order to construct and index based insurance, as described by equation (2): i) consequential loses assessment, and ii) weather data.

Weather data was retrieved from the national weather and hydrology institute (SENAMHI). Data coverage was remarkably good; however, imputed data were introduced for missing values. More details on Nogales and Córdova (2013). Figure 3 shows the number of missing daily values for the entire sample of years considered.

Figure 2. Number of Missing Days of Data per Year

Source: Nogales and Córdova (2013)
The climate data was reasonably well approximated with a lognormal distribution, with mean value equal to 5.584, and sample standard deviation equal to 0.226.

Table 1 presents some relevant features of weather and output distributions.

**Table 1. Rainfall Distribution Statistics, 1967 – 2012.**

<table>
<thead>
<tr>
<th>Lognormal Distribution</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>5.584</td>
</tr>
<tr>
<td>Std. Dev</td>
<td>0.226</td>
</tr>
<tr>
<td>KS Stat</td>
<td>0.084</td>
</tr>
<tr>
<td>p- value</td>
<td>0.895</td>
</tr>
<tr>
<td>JB Stat</td>
<td>1.222</td>
</tr>
<tr>
<td>p - value</td>
<td>0.543</td>
</tr>
</tbody>
</table>

Source: Nogales and Córdova (2013)

Consequential losses were constructed using crop simulation models. FAO’s water stress crop simulation model, AQUACROP, was used to estimate the yield losses experienced due to insufficient levels of rainfall for two varieties wheat and potato varieties (Nogales and Córdova, 2013). Crop simulation models replicate growth behavior of the cultivar under different climate conditions, prevalent at different stages in the phonological process. It is argued that they fail to provide robust estimates in the case of extreme events (Miranda, 2008). However, given the nature of the problem tackled in the project (drought can only cause damage up to a certain level, i.e. all the seasonal harvest is lost), this concern, despite relevant, may not necessarily entail significant biases in the estimation of consequential losses.

Based on the results of the crop models, critical, rainfall dependent, phonological stages were identified and the weather data associated to these timeframes used as regressors to predict the observed yields. Thus, conditional on weather data $X$, the predicted value of output can be represented by:

$$ y = X \cdot \beta + \varepsilon, \text{such that } \varepsilon \sim \text{Normal}(\mu, \sigma). $$

**Table 2. Consequential Losses Drought Model**

<table>
<thead>
<tr>
<th>Explained var: Yield (%)</th>
<th>Value</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall_at_4th_decadal</td>
<td>0.004113</td>
<td>***</td>
</tr>
<tr>
<td>DUMMY1990</td>
<td>-0.49932</td>
<td>***</td>
</tr>
<tr>
<td>DUMMY2001</td>
<td>0.497055</td>
<td>***</td>
</tr>
<tr>
<td>DUMMY2010</td>
<td>-0.422391</td>
<td>***</td>
</tr>
<tr>
<td>Trend</td>
<td>0.024</td>
<td>***</td>
</tr>
</tbody>
</table>
### Table 3. Consequential Losses Excess Rain Model

<table>
<thead>
<tr>
<th>Explained Variable: Ln(Yield)</th>
<th>Model 1</th>
<th>Model 2</th>
<th>Model 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Variable</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rainfall_at_4th_decadal</td>
<td>0.01465</td>
<td>***</td>
<td>0.01583</td>
</tr>
<tr>
<td>Rainfall_at_4th_decadal^2</td>
<td>-0.00015</td>
<td>**</td>
<td>-0.00021</td>
</tr>
<tr>
<td>Rainfall_at_critical_stage</td>
<td>-</td>
<td>-</td>
<td>0.00577</td>
</tr>
<tr>
<td>Constant</td>
<td>-0.64955</td>
<td>***</td>
<td>-2.59687</td>
</tr>
<tr>
<td>Adj. R2</td>
<td>0.73</td>
<td>0.77</td>
<td>0.78</td>
</tr>
<tr>
<td>N</td>
<td>45</td>
<td>45</td>
<td>45</td>
</tr>
</tbody>
</table>

1% significance ***
5% significance **

Source: Nogales and Córdova (2013)

The combined error structure of predicted outputs and weather will be assumed to be independently distributed for all periods in the sample. This assumption can be later relaxed by using Monte Carlo simulations to obtain the relevant moments for the expected losses distribution. The error structure of equation (2) will then become:

\[ E[\epsilon, \lambda(x)] = 0 \]

### 4. Preliminary Results from the Case Study

#### a. Redefining the Catastrophe Level of Rainfall
The results presented below are based on ten thousand Monte Carlo simulations constructed upon the data and assumptions described below.

INSA is planning to release a new edition of the SAMEP program for 2014. Some preliminary figures suggest that the price paid by rural producers should not exceed 100 Bs/Hectare (something like 10 US$/Hectare). This will be considered as the upper limit of the WTP parameter. A national agriculture Census is planned to be launched in 2013 and 2014, and it would be advisable to include producers’ willingness to pay, at least in some of the prioritized poorest municipalities.

In addition, some other parameters were assumed, summarized in Table 5:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>α</td>
<td>30.00%</td>
<td>Precautionary and other regulatory reserves + return for shareholders</td>
<td>Law 1883 and complementary legislation</td>
</tr>
<tr>
<td>Administrative Expenses</td>
<td>30.00%</td>
<td>Costs of delivering services in rural areas</td>
<td>Benchmark</td>
</tr>
<tr>
<td>WTP</td>
<td>14.49</td>
<td>Gross Willingness to pay for the premium</td>
<td>INSA</td>
</tr>
<tr>
<td>net_WTP</td>
<td>9.57</td>
<td>WTP net of administrative costs and alpha</td>
<td></td>
</tr>
<tr>
<td>Costs</td>
<td>536.00</td>
<td>Costs of producing wheat in Anzaldo in US$/ton</td>
<td>Nogales and Cordova</td>
</tr>
<tr>
<td>Costs</td>
<td>429.00</td>
<td>Costs of producing wheat in Anzaldo in US$/ha</td>
<td>Nogales and Cordova</td>
</tr>
<tr>
<td>Max_coverage</td>
<td>343.04</td>
<td>Maximum reimbursement paid to producers</td>
<td>Nogales and Cordova</td>
</tr>
<tr>
<td>y_trigger</td>
<td>0.64</td>
<td>80% of expected output</td>
<td></td>
</tr>
<tr>
<td>x_trigger</td>
<td>340.6</td>
<td>Rainfall level (in mm)</td>
<td></td>
</tr>
<tr>
<td>cum_prob(x_trigger)</td>
<td>86.24%</td>
<td>Cumulative probability at trigger index</td>
<td></td>
</tr>
</tbody>
</table>

Source: Authors’.

i) A fixed amount of administrative costs for delivering financial services in rural settings was assumed. This figure was based benchmarked to the costs of providing credit services in rural areas by financial development institutions in Bolivia;

ii) The index trigger level below which the insurance pays off is defined as the amount of rain necessary to achieve a predicted level of yield of 90%, in the case of drought, and 80% in the case of flood. Estimated using information in Tables 2 and 3.

iii) The initial catastrophic level, \( x_{cat} \), was set at 0mm, an iteratively increased up until a newly defined level of catastrophe \( (x_{cat'}) \) fulfilled the demand side restriction, defined by (3). For the case of excess rain, the trigger was initially set at 400 mm (the predicted necessary rainfall to achieve \( y_{\text{trigger}} \) levels of output).
iv) The insured value was established as the cost of production for a trigger level of production. i.e. 90% of the expected yield\(^8\).

v) Regulatory costs are defined by Law 1883 and complementary legislation. Average profit margin in the insurance industry in Bolivia reaches 15% (Nogales, et al, 2012). Added up together, the regulatory costs were estimated in 33% of the price of the premium, or \(\alpha = 0.3\) in equation (1).

vi) The cost of production was estimated in 536 US$/ton (3700 Bs/ton). Given the expected yield of 0.8 ton/ha, the average cost per hectare reaches 429 US$.

vii) The maximum reimbursement to be paid to smallholder – farmers reaches 343 US$/ha.

Table 5 presents the results of the exercise. They should be considered as preliminary, and provide only a flavor of the concept here presented.

The demand restriction, defined by the net willingness to pay, entails that only up to 21% of the consequential losses could be insured via commercial schemes. Rural small – holders are covered from losses as small as 10% of their expected outcome. This in turn implies that the insurance pays on a very frequent basis: 1.36 years on average. Despite this fact, private or commercial firms would get the mean return of the industry for the Bolivian market, ie 15% annually; the size of the business would then depend on the number of policies finally sold.

### Table 5. Results, Redefined Catastrophic Levels, Drought – Wheat

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Commercial Catastrophe</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expected Loss</td>
<td>9.2</td>
<td>US$</td>
</tr>
<tr>
<td>(x_{cat}^*)</td>
<td>307.2</td>
<td>mm</td>
</tr>
<tr>
<td>(y_{cat}^*)</td>
<td>0.502</td>
<td>ton/ha</td>
</tr>
<tr>
<td>(\delta_{cat}^*)</td>
<td>-21.0%</td>
<td></td>
</tr>
<tr>
<td>(\text{cum_prob}(x_{cat}^*))</td>
<td>73.7%</td>
<td></td>
</tr>
<tr>
<td>Average Frequency of payment</td>
<td>1.360</td>
<td>years</td>
</tr>
<tr>
<td><strong>Output Catastrophe</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(\delta_{cat_total})</td>
<td>-90.0%</td>
<td></td>
</tr>
<tr>
<td>(y_{cat_total})</td>
<td>0.080</td>
<td>ton/ha</td>
</tr>
<tr>
<td>(x_{cat_total})</td>
<td>204.500</td>
<td>mm</td>
</tr>
<tr>
<td>(\text{cum_prob}(x_{cat_total}))</td>
<td>12.2%</td>
<td></td>
</tr>
</tbody>
</table>

Source: Authors'.

---

\(^8\) The expected yield is 0.8 ton/hectare, and the average cost of production was estimated in 530 US$/ton. More details on the data at Nogales and Córdova (2013).
Crop insurance has the peculiarity that consequential losses are bounded. Below (or above in the case of flood) a certain level of rainfall, the costs of harvesting surpass the benefits from harvested yields. At this level, losses can be considered as absolutely catastrophic. Thus a second level of catastrophe needs to be defined, $X^-$ as defined by equation (4). In the case of drought - wheat a level of losses superior to 90% is considered as ultimately catastrophic. The second part of Table 5 offers some statistics of the

b. Optimally Allocating the Risk Among Different Financial Instruments

it is now necessary to first estimate the expected losses, given the catastrophic levels defined by Table 5, and subsequently allocate the costs of this risk among the three different financial instruments considered. The latter step is made by dividing the share of the total cost regarded now as catastrophic into smaller layers or buckets of costs. As was mentioned before, 21% of the costs were to be covered by a commercial insurance scheme, paid by small holder farmers; the remaining 79% is now to be allocated into 5 adjacent layers of risk. For each of these buckets, a cost minimization algorithm was implemented to determine the optimal allocation of risk according to equations (5.1) to (5.3).

Other relevant parameters utilized to estimate equation (5) are described in Table 6.

Table 6. Parameters used to Estimate the Risk Allocation

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\phi$</td>
<td>125.00%</td>
<td>Average charge upon catastrophic risk</td>
<td>Reinsurance industry</td>
</tr>
<tr>
<td>$l_s$</td>
<td>12.67%</td>
<td>Social discount rate used to evaluate public programs</td>
<td>Bolivian Government</td>
</tr>
<tr>
<td>$s_g$</td>
<td>4.88%</td>
<td>Rate at which Bolivian Government issued sovereign debt in 2013</td>
<td>Bolivian Ministry of Finance</td>
</tr>
<tr>
<td>$r$</td>
<td>4.00%</td>
<td>Interbank interest rate at July, 2013</td>
<td>Bolivian Central Bank</td>
</tr>
<tr>
<td>Libor</td>
<td>0.40%</td>
<td>LIBOR</td>
<td>Global Rates</td>
</tr>
<tr>
<td>$l_f$</td>
<td>2.50%</td>
<td>Front end fee upon loan disbursement</td>
<td>World Bank IFL (2013)</td>
</tr>
<tr>
<td>$l_r$</td>
<td>Libor +1%</td>
<td>Actual interest rate for maturity loans above 15 years</td>
<td>World Bank IFL (2013)</td>
</tr>
<tr>
<td>$l_c$</td>
<td>0.50%</td>
<td>Stand - by fee</td>
<td>World Bank IFL (2013)</td>
</tr>
<tr>
<td>$m$</td>
<td>18</td>
<td>Maximum maturity available</td>
<td>World Bank IFL (2013)</td>
</tr>
</tbody>
</table>

Table 7 presents the results of the exercise. They should be considered as preliminary, and provide only a flavor of the concept here presented.

Table 5. Results from Risk Allocation

Source: Authors’.
5. Conclusions

The framework here presented may constitute an alternative to implement index based insurance schemes in poor, rural settings. The proposal suggests for both public and private participation; public subsidies should be introduced where the main market constraints become binding.

The approach may be appealing for at least two reasons. First, it may help to create markets for index based insurance in the long run. International experiences suggest that rural smallholders tend to distrust insurance schemes if they don’t payback on regular basis. The introduction of a scheme of this type may have a demonstration effect, helping both private providers and consumers to learn about the costs and benefits of the insurance.

Second, national and regional governments may use this approach as tool to reduce the burden of cost associated to providing transfers to poor communities. The case of Bolivia is illustrative in this regard. Our preliminary results suggest that INSA would save up to xxx million dollars by adopting the framework here developed.

However, the approach should be considered with caution as the solution here proposed may lead to dynamic adverse selection problems. Smallholders, already aware of the mechanism rules may declare WTP considerably below their true valuations. Mechanisms that gradually reduce small–holder farmers` dependence on the scheme should be considered at the time of implementing the subsidies.

For the particular case of Bolivia, it would be more than interesting to do further research in order to investigate the potential benefits from the approach here presented in order to expand the coverage of the SAMEP to regions where sufficient climatic information data is available. Contingent credit has shown its capacity to increase the ability of governments to self–insure by relaxing their short term liquidity constraints.
References


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