Comprehensive Disaster Risk Modeling for Agriculture

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Abstract – The paper identifies the needs of the public sector (governments) to have access to comprehensive disaster risk models for agriculture (‘AgriCat’) capable of quantifying the risk across the entire agricultural enterprise. This is particularly the case for countries exposed to disasters, where significant proportions of economic activity, poverty eradication, human development, and livelihoods are associated with agriculture. The proposed AgriCat risk modeling framework is based on the principles of structured physical risk modeling for property CAT risk, employing the probabilistic event based approach. It delivers four outputs relevant for the agricultural enterprise: a) loss of capital stock (barns, equipment, land, etc.), b) direct loss of income (from crops, livestock, fish etc.) due to the disaster, c) loss of nutrition (i.e. in particular when production is providing nutrition to the producer), and d) indirect loss of future production (in years following the disaster). The outputs also include “functionality restoration time” information – defined as time to replant and grow to maturity the crops (seasonal and permanent), and time to repair and restore functionality of other capital assets (e.g. Livestock, warehouses, silos, the land, etc.). Fully accounting for the disaster impacts using this modeling approach would enable governments to promote, comprehensive agricultural risk management programs, involving improved resilience of the agricultural sector as well as risk transfer through insurance / reinsurance mechanisms.

Keywords – comprehensive disaster risk modelling for agriculture, AgriCat modelling, holistic risk management, agricultural risk, public private partnerships, disaster risk quantification, public agricultural enterprise

1. Motivation

In low income and developing countries agriculture is a significant part of the economy providing income and substance to the rural poor, and where poverty is combated through a variety of rural and agriculture related initiatives. When disasters strike, as manifested in numerous historical disasters, the impacts can have a profound deleterious effect on poverty eradication, and human development indicators. These countries need comprehensive risk management programs across the agricultural enterprise to manage these disaster risks holistically.

Governments in these countries are increasingly looking to establish public private partnerships (PPPs) to manage disaster risk, in particular through insurance. While the current focus is on crop insurance, in many countries there may be the potential for much more significant disaster losses far beyond the capacity of crop insurance schemes to cover. In the conversations aimed at establishing PPPs for comprehensive agricultural risk management, the governments need to consider the potential for all facets of risk to the agricultural sector as well as the requirements of models to assess the risk of these outcomes and provide the basis for risk transfer mechanisms. Such models would need to provide output metrics beyond financial loss for all parts of their agricultural enterprise, such as loss of capital stock (barns, equipment, land, etc.), direct loss of income (from crops, livestock, fish etc.) due to the disaster, loss of nutrition (i.e. in particular when production is providing nutrition to the producer), and indirect loss of future production (in years following the disaster). Based on these risk metrics governments could seek risk transfer solutions that best protect their entire agricultural enterprise and development goals.

This paper sets out the steps of how to create comprehensive agricultural exposure, and how to apply the principles of structured risk modelling based on the procedures established for analysing property Catastrophe risks to the insurance industry.
2. Agriculture Disaster Risk - Low Income & Developing Countries

Low income and developing countries have significant participation of the agricultural sector to the country’s GDP. In such countries disasters can have profound impacts on the agricultural sector and consequently on their economic development, poverty eradication efforts, and human development. Agriculture is a source of employment and income, contributes to a country’s food security, generates export revenues, sustains rural development, it provides nutrition and livelihoods for poor farmers, it is an important part of poverty eradication initiatives, and it supports human development of the poor. Laframboise and Loko (2012) cite research findings that disasters have a significant negative impact, including long term impacts on growth, poverty and social welfare as well as the danger of poor being pushed into „poverty traps“. As a result rural agriculture is widely supported by donors and NGO’s.

As an example, figure 1 portrays some countries with high exposure to catastrophes where significant proportions of economic activity and livelihoods are associated with agriculture in Central America, the Caribbean, South Asia, and Southeast Asia. Central American and Caribbean countries - Honduras, Nicaragua, Guatemala, and Haiti are exposed to hurricanes, flooding, earthquakes, landslides, periodic droughts and some volcanic activity, and have experienced extreme disaster losses in the past. The three countries in South Asia – Pakistan, Bangladesh and Myanmar are all populous, and heavily dependent on agriculture (dominated by small holders). Pakistan is exposed to earthquakes and monsoon driven flooding, as well as occasional droughts. Bangladesh has been exposed to droughts, cyclones and floods (much of the country is inundated during the summer monsoons). Myanmar has much the same perils as Bangladesh, plus significant earthquakes and landslides. In Southeast Asia - Philippines, Vietnam and Indonesia, although not low income countries, are similarly impacted. Indonesia is affected by earthquakes, tsunamis, eruptions, floods and droughts. Philippines is exposed to typhoons, landslides, earthquakes, tsunamis and volcanism, while Vietnam has some typhoon exposure, and is heavily exposed to catastrophe flooding in the Mekong and Red River delta. African countries – Mozambique, and Madagascar depend heavily on agriculture and have been historically exposed to droughts, cyclones and floods.

The horizontal axis reflects the contribution of the agricultural sector to country’s GDP, the vertical axis the participation of the agriculture labor force in the country’s labor force, and the size of the circles and the labels the percentage of the population living under the poverty line.

A brief review of the impacts of the 1998 hurricane Mitch on the agriculture enterprise of Honduras is helpful to identify the needs for comprehensive agricultural risk modelling form governments and public sector perspective. UNDP BCPR (2013) summarizes the effects of Mitch with more than 14000 fatalities, one third of the population being affected, and with inflicted economic damages of USD 3.8 billion (almost three-quarters of the total GDP in 1998). Damages to the agricultural sector have been estimated as USD 2 billion contributing over 50% to the total economic loss (ibid). Honduras agriculture is dominated by small holders and poverty eradication efforts by the government significantly rely on financial support by various donors (IFAD 2011). The impact on the production of the principal industrial and export crops (bananas, sugar, cane, coffee, melon and African palm), which significantly contribute to country’s export and foreign currency revenues, is shown in figure 2 on the left. The right hand side of figure 2 illustrates that the direct losses (within the year) contributed only about 25% to the total loss for industrial and export crops due to the losses to permanent crops that required between 2 and 7 years to reach pre-disaster production levels (ECLAC 2003).

Hurricane Mitch increased the incidence of infant and child malnutrition up to three times in Nicaragua (that was also heavily impacted by the disaster) Rentschler (2013). Further evidence of long term negative impacts on welfare indicators of households, such as consumption, earnings and labor market outcomes, has been presented for several countries including Honduras. After hurricane Mitch Honduras households earning less than $250 per
person per year were unable to fully recover their pre-disaster asset levels even in the long term (ibid).

The effects of the 2010 Pakistan floods further illustrate the devastating impacts of disasters on agriculture and subsequent economic impacts for low income and developing countries. The 2010 Pakistan floods affected 20 million people, with almost 1800 fatalities, and 1.6 million homes being affected (Hoffmaister et al., 2012). The cost of damages has been estimated at $10 billion, with the agricultural sector contributing 50% of the total. Recovery and reconstruction costs have been estimated in the range of $6.7 to $8.9 billion. Heavy dependence of Pakistan economy and development policies on agriculture resulted in profound economic losses – loss of 5.3 million jobs, drop of the predicted GDP of 4.5% to -2% to -5% and increase of the country indebtedness from IMF for the recovery costs (ibid). Between 60 and 88 percent of the farming households in Pakistan reported losses of more than 50 percent of their major crops: rice, vegetables, cotton, sugar and fodder. The Pakistani government reported that the disaster severely impacted poverty reduction efforts leading to increases in poverty driven by the loss of assets and sources of livelihoods. As per the World Food Program report, 70% of the Pakistani population, mostly in the rural areas, did not have access to proper nutrition, with an associated long term impact on human development and increase in poverty. A 2013 report estimated that the Pakistan economy grew at an average rate of 2.9 percent per annum for three years after the disaster, which is less than half of the 6.5 percent achievable growth in the absence of human and economic losses from the floods.

The above examples highlight that in low income and developing countries disasters can have profound impacts on the agricultural sector and consequently on their economic development, poverty eradication efforts, and human development.

The agricultural enterprise in a low income country comprises a number of stakeholders (ministries of agriculture, economic development agencies, banks, international organizations – e.g. UN / FAO, as well as international development agencies and donors. While there will be a focus on immediate financial losses, of greater concern will be long term losses (in the years following the disaster) with impacts across the entire agricultural enterprise – including loss of livelihoods, loss of nutrition, and negative impacts on poverty and human development.

Figure 3 conceptually summarizes the smallholder agricultural enterprise that needs to become more resilient to disasters. The horizontal axis in figure 3 captures the loss components, while the vertical axis portrays the loss takers. Figure 3 reflects the current reality that most of the catastrophic agricultural losses across the entire agricultural enterprise are taken by the poor farmers which creates significant liabilities of the governments for the wellbeing of the farmers.

In this situation, disaster affected countries where significant proportions of economic activity, human development, and livelihoods are associated with agriculture require comprehensive disaster risk management programs across their entire agricultural enterprise.

In order to design, assess and stress test such programs the governments need access to models that would provide quantitative risk metrics for the entire agricultural public enterprise.

3. Comprehensive Disaster Risk Modeling for Agriculture (AgriCat Modeling)

Previous two sections highlighted the need of governments to have access to comprehensive disaster loss modeling for agriculture. In this section, we provide details what is needed and how such ‘AgriCat’ models could be build.

Disasters are rare events with severe consequences. The historical record of disasters is too short to provide a comprehensive sample of all the extreme events that can happen. Hence it is necessary to create a stochastic set of potential events, in effect a representation of all the extremes that would be experienced over a period of tens of thousands of years. Then it becomes possible to explore what magnitude of impacts can be expected at a range of relevant return periods (or annual probabilities) as an objective measure of the disaster risk, along with the average annualized cost of that risk. The degree of de-
As with risk modeling for property, comprehensive agriculture disaster risk modeling will require different inputs and risk metrics according to the stakeholder. However, the basic architecture of such models has much in common with insured property loss modeling and for many of the perils the hazard models can be the same.

Agriculture includes a diverse range of activities. For example:

- Salmon are farmed in giant cages submerged 30 ft. under water, sometimes tens of miles from the nearest coastline. This type of aquaculture is exposed to a range of hazards — among which will be extreme waves accompanying major storms. When cages are breached or torn apart, or moorings are broken, the fish can escape, when there will be direct losses to the tools for production (cages, mooring, etc.) as well as loss of product, i.e. the escaped fish.
- In Asian and Central American countries (China, Philippines, Honduras, Nicaragua) shrimp farming has grown into an important sector of the economy, in particular for the coastal rural populations. The principal hazard can be storm surge or tsunami flooding, damaging the pond facilities and washing away the stock.
- Another very widespread and equipment-intense form of agriculture at middle latitudes employs green houses and cloches made of either glass or plastic sheeting to grow early season flowers, vegetables and fruits. In higher latitudes these facilities will have computer controlled heating and cooling facilities and artificial lighting. The Netherlands is the largest
greenhouse producer with more than 10000 hectares under glass houses. The principal perils to these facilities are hail and wind. If damage happens in the winter season then the production in the facility may all be lost to frost.

To outline how agricultural models should be structured we need first to develop a map of all the ways in which damage and losses can be caused, and then to follow the consequence of these impacts on the agricultural production, and into the resulting losses in incomes and food for consumption.

Losses can be classified into three categories:

a. Losses to assets involved in agriculture (such as equipment, barns, roads, land etc.)
b. Short-term losses to agricultural production within the season (either through direct impact of the hazard agent on the crop, or indirect as through damage to equipment, loss of manpower, access etc.)
c. Long term losses to agricultural production over multiple seasons, including permanent losses.

Clearly losses to assets may or may not have consequences to production. Many losses to production will have an impact only over a single season, but some will have consequences for multiple seasons.

It is worth exploring the definitional difference between an asset involved in agricultural production and the production itself. For example a sheep is an asset to produce both milk and wool. A walnut tree is an asset for producing walnuts. However the sheep can also be sold as food, just as the walnut tree can be sold as firewood but then there is no more production of milk, wool or walnuts (as well income from this production).

The principle of the modeling is to quantify impacts in terms of lost value, and lost production. These estimations of short and long term, direct and indirect damages, could then, for example, be fed into separate micro- and macro-economic models to show the expected impacts on local poverty or on national policies and economies.

3.1. Disasters and Agro Hazards

Disasters affecting agriculture can include Flood, Frost, Droughts, Typhoons (wind, flood, and landslides), Earthquakes and volcanic eruptions.

Floods can be associated with flash flooding from intense rainfall as well as extended inundation on major river systems. Long lasting flooding (water logging) could prevent replanting of crops, or for certain crops may cause rotting of the roots and loss of the harvest or loss of the plants. Droughts will tend to be regional in extent; the most severe and persistent may last for more than one growing season.

Earthquakes affect mostly the farm buildings and infrastructure, although in steep terrain earthquake-triggered landslides may cause losses to the agricultural land and planted crops. A major earthquake may also seriously damage the roads, silos and warehouses, thus impacting local access to food. An earthquake could also lead farmers to abandon the fields to deal with the emergencies and repairs of their houses, thus impacting production.

For volcanic eruptions the chief peril will be ash fall. While causing short-term damage to foliage on crops and trees in the long term the ash can fertilize the soil and increase productivity. For farms close to a volcano, damage can be caused by blast damage, by fire or even by lava flows.

Some disasters such as tropical cyclones and floods will have their own seasonality. Others can happen at any time in the year. The timing of the disaster relative to the growing calendar can have a big impact on the agricultural losses. If a disaster (such as a typhoon) strikes in the early stages of development (e.g. in the vegetative or flowering phase) it may be possible to re-plant and salvage (at least part of) the harvest. If it strikes just before the harvest is collected the lost production may be total. The impact will largely depend on the resilience of the crops affected, as well as on the ability of producers to mitigate the long term losses.

Where there is extensive damage to permanent crops (e.g. bananas, coffee, fruit trees...) it may take several years for replanted crops to reach maturity and full production, leading to indirect long term losses. Therefore it is important to distinguish between seasonal crops with their annual or more frequent sowing cycles and permanent orchards, plantations etc., as well as the differences in the susceptibility to damage of the different plants. For example, 1974 hurricane Fifi made landfall in the northeastern part of the Honduran Atlantic coast, and damaged an area of highly productive land that was home to livestock, banana, African (oil) palm, maize and rice cultivation. Banana plantations were practically destroyed. Seasonal crops - rice and maize in the flooded area were washed away. However more resilient oil-palm plantations nearby sustained the strong winds and more than two weeks of flooding without significant long term damage. Extreme flooding in high relief landscapes can lead to losses of the fertile top soil. Eroded land may not be worth recovering in particular where steep terraces are destroyed.

Livestock caught in the inundation of a broad flood plain is highly vulnerable. In the 2010 Pakistan Floods 1.2 million of livestock (excluding poultry) died, while in Honduras 50000 heads of cattle were drowned in the flooding that accompanied Hurricane Mitch.

Direct and indirect disaster losses can also be generated in fishing and fisheries. For example, Hurricane Mitch damaged 365 fishing vessels (from both artisan and industrial fleets) and also caused direct damages to the very profitable coastal aquaculture production of shrimp, by flooding the fishing ponds, destroying the larvae for restocking the ponds, and damaging the packing facilities. The indirect damage was estimated as 2.5 times the value

http://www.eclac.cl/publicaciones/xml/4/12774/1cmexg5i_VOLUME_IIIn.pdf
Figure 4: Risk modeling requires that all components of the exposure across the entire agricultural enterprise (physical and human) to be captured by a Geographic Information System (GIS) database. For each segment of the enterprise agricultural assets at risk should be identified and classified (e.g. land, infrastructure, facilities, tools and equipment, crops in the fields, crops in storage, livestock in facilities, etc.).

of the annual shrimp harvest, including the value of lost income over the time taken to bring the ponds back to the pre-disaster levels of production (ECLAC 2013).

In evaluating the impact of the production losses on impoverishment in low income countries it may be helpful to distinguish between losses to crops that provide household sustenance and those additional crops that generate income. Loss of sustenance and income has particularly acute impacts on child health, schooling etc. with associated long term implications.

3.2. Exposure for AgriCat Modeling

Agricultural disaster modeling needs to capture all the relevant exposure information for the quantification of direct and indirect damage of the agricultural enterprise, operating over both short term and long term. The structure of a comprehensive Exposure Database intended to capture the principal elements of disaster agricultural loss is shown in figure 4.

All components of the exposure should be captured by geo-referenced location typically employing a Geographic Information System (GIS) database. At a minimum the resolution of such data would typically follow the finest resolution administrative divisions at town or parish level. This will also be the resolution at which production and other agriculture related data are typically aggregated. Placing all agricultural exposure information on a GIS platform makes it possible to overlay the exposure with modeled hazard footprints for the quantification of the disaster losses. Where statistics on agriculture are not available at the highest administrative resolutions, it may be necessary to disaggregate the data to the finer resolution by using satellite observations of agricultural land cover.

For the purposes of risk modeling we need the different categories of agricultural exposure classified and identified. This could include the area under cultivation of different crops (such as cereals, fruit, fish, prawns etc.), crop varieties, and their growing seasons. Also, we need to include the nature and values of agricultural equipment that could, for example, be lost in an extreme flood as well as the nature and values of the infrastructure that supports the farming whether it is greenhouses, fish ponds, fish cages, irrigation equipment etc. We also need details of the buildings that support the agriculture, including those used to protect equipment, or store the harvest and agricultural inputs (e.g. seeds and fertilizers).
Lastly we require geo-referenced information to find which lands are located within the floodplain and which are susceptible to landslides (according to the slope of the terrain and the underlying geology).

Key elements of the exposure or assets at risk in figure 4 comprise six principal categories:

1. Agricultural (farm) land & Infrastructure
2. Agro facilities (buildings and structures)
3. Tools and Machinery
4. Agricultural products in production (crops and livestock)
5. Products in storage and facilities (harvested crops, battery livestock, agro inputs, etc.)
6. People whose labor is required to support the agricultural production, and whose livelihood depends on agriculture.

Figure 4 articulates the type and general information format of the capital assets at risk that need to be assembled by GIS resolution level and by producer type. Agricultural producers, their farming and husbandry practices, their equipment, their incomes, their products distribution etc. are specific to the social and political environment of a country. Generally we grouped them into smallholders and marginal farmers, cooperatives, independent producers, and corporations. The category of assets is similar across all types of producers (from smallholders to large plantations), though specific details and values may be very different (e.g. between equipment owned by smallholders and that held by industrial-scale agricultural producers).

There are two basic crop production cycles – seasonal and ‘permanent’. Seasonal production requires planting, growing to maturity, and harvesting the crops every growing season. Grains are typical seasonal crops. Permanent production involves planting, growing the crops to maturity a year or more, and then having recurring harvest cycles. Trees (fruits, nuts, etc.), bushes (coffee, tea) are typical permanent crops. The distinction between seasonal and permanent crops is important and necessary for estimation of the direct (short term) and indirect (long term) losses.

Exposure data should also include information on the entity whose income and livelihood depends on agricultural production – from small holders, to large scale industrial farming operations. Women are particularly critical for smallholder agricultural production, and can also be the most vulnerable to a loss in small scale food production. Figure 4 contains an example of information necessary to model the impact of disaster on the human capital involved in agriculture, including the role of local agriculture in providing nutrition.

3.3 Disasters and Agricultural Vulnerability Modeling

In order to model the impact of the hazard on the exposure it is necessary to know the vulnerability of the different agricultural assets. Vulnerability needs to address the direct impact of the hazard on the producing asset, as well as the indirect loss of production as a consequence of the degree to which the farm has the ability to restore the asset and the production to the pre-disaster level.

Direct and indirect losses require different measures:

a. Direct losses – measured through the direct loss of the agricultural assets affected (e.g. for crops and livestock as loss/reduction in the expected production, and for buildings and infrastructure as percent of the replacement value). This loss could be total or partial loss.

b. Indirect losses – measured by the “down time”, or time needed to bring the production back to pre-disaster level after re-planting the crops. Re-planting may for example be prevented by the effects of the disaster (e.g. water logging, extended floods, or drought preventing planting for extended periods). Seasonal crops (annual or more frequent sowing cycles) could be brought back into production in the next season provided that other agro inputs are available, even earlier if the growing season could be salvaged with re-planting in the same season (depending on the time when the disaster strikes). Permanent crops may take several years to reach maturity, e.g. walnuts 5 to 7 years, coffee about 4 years, bananas 8 to 12 months, etc. Future livestock productivity could also be impacted by the stress to the animals caused by the disaster (cattle losing weight, dairy cows reducing milk production, etc.). Data on the expected physical volume of production by crop of interest (including long time series of data on production, planted areas, and yields) will be required so as to quantify the indirect physical losses. The notion of direct and indirect loss in agriculture is similar to the notion of property and business interruption loss in conventional disaster loss modeling for insurance. The development of the relevant vulnerability functions requires specific expertise on crop sensitivity to the various hazards, such as droughts, strong winds, flooding, ash fall etc.

3.3.1 Wind Vulnerability

Buildings, barns, warehouses, packing, processing, harbor facilities, etc. are affected by strong winds in the same way as other buildings and facilities included in property catastrophe loss modeling. Damage from wind and water ingress is considered in terms of the percent loss of value for that building type and occupancy relative to the wind speed. The range of structures included would range from warehouses down to small storage barns. Machinery and equipment classed as ‘Contents’ could be stored in the agricultural facilities (e.g. drying, packaging and other equipment), or directly exposed to the wind (e.g. a water supply tower with a tank on the top). Barns may also contain stores of fertilizers, or seeds that could be ruined by water ingress. Barns may also protect animals such as pigs or battery chickens, which will suffer large scale mortality should the building collapses or through the inability to provide heat during winter.
Products in the field include standing seasonal crops, permanent crops, and livestock. In general, livestock, in the fields and on the pastures is not very sensitive to wind. Windthrow to trees is very species dependent, although most data on the subject has been developed for forest trees, as for studies in Puerto Rico after category 4 hurricane Hugo in 1989⁷. In the early stages of development of cereals (e.g. corn) high winds can cause root lodging or stem breakage⁸. Root lodging occurs most frequently during the mid-growing season before brace roots are established and when soils are wet. Greensnap, on the other hand, occurs when the force of the wind is sufficient to cause the stalk to break and is most common during rapid vegetative growth and before stems mature and are lignified. Damage to cereals and seasonal crops is crop and species specific.

3.3.2. Flood Vulnerability

Flood modeling needs to include not only the flood depth and duration at a location, but also consider situations in mountainous terrain when agricultural land is damaged through significant erosion or from stones on the fields. In such situations the degree of potential erosion or deposition could be a component of the flood loss modeling. Flooding has the potential to destroy any equipment that is inundated, including barns and houses. Animals housed in barns are extremely vulnerable if they cannot be evacuated.

Crops and livestock in the fields in areas of strongest flooding are typically swept away or drowned. Flood vulnerability of the crops is a function of the flood depth, and duration of the flood. Flood tolerance of permanent and seasonal crops is species dependent, and it should be taken into account in evaluation of the loss due to flooding (water logging). Seasonal crops are typically not very flood tolerant. For example, while rice is a crop which requires a lot of water, most of the standard varieties cannot withstand stagnant flooding for more than about a week, as it prevents the plant accessing the necessary sunlight and essential gas exchanges. (Floods in 2006 in the Philippines resulted in a rice crop loss of $65 million⁹).

Permanent crops (e.g. trees) are generally more flood tolerant. The interaction between the soils, the trees and the flood characteristics determines the flood tolerance of the trees⁹. During flooding soil is affected by poor soil aeration creating oxygen deficiency for the tree, the most important environmental factor. Adult healthy trees tolerate flooding better than younger or older trees.

3.3.3. Landslide Vulnerability

Landslides (including mud flows) could be activated by various triggers - earthquakes, excessive rainfall, and hurricane induced rainfall. They occur in hilly / mountainous areas when slopes lose their stability as a result of the strength of shaking, depth of saturated soils, or lack of vegetation on the slopes. Landslides will cause high losses to all agricultural assets in their path.

3.4. Components of AgriCat Models

AgriCat, i.e. a comprehensive agricultural disaster risk model, needs to account for all relevant exposure categories in the assessment of the total impact on the agricultural enterprise. It should include all the principal loss causing hazards, contain the ability to quantify the vulnerability of the exposure to these hazards, and provide relevant risk metrics or outputs. AgriCat risk model needs to provide outputs relevant for the agricultural risk stake holders, which can be fed into other models, such as macroeconomic and agricultural economics models. For all these different purposes the outputs could be separated into the following categories:

- Loss of capital stock (barns, equipment, land, etc.)
- Direct loss of income (from crops, livestock, fish etc.) due to the disaster
- Loss of nutrition (i.e. in particular when production is providing nutrition to the producer)
- Indirect loss of future production (in years following the disaster)

These model output categories should provide the required risk metrics from the perspective of all the various stake holders. To aggregate different loss categories, as well as to aggregate disaster risk with other risks, it is necessary to monetize the loss. This may require additional information: the replacement value of the capital stock, prices per unit of agricultural production (crops, livestock, etc.).

Model outputs for indirect losses, which are driven by the time needed to restore the production and the income streams, would include “functionality restoration time” – representing time to replant and grow to maturity the crops (seasonal and permanent), and time to repair and restore functionality of other capital assets (e.g. warehouses, silos, the land, etc.). The model should help identify where the highest losses are likely to be situated and hence which farms will be worst impacted.

Consistent with standard catastrophe loss models, AgriCat risk model has to be stochastic (probabilistic) and event based, covering all extremes that would be experienced over a period of at least 10000 years. Losses for each stochastic event, together with a measure of uncertainty around the losses, would be generated and stored in an event loss table or ELT. From the ELT an Exceedance Probability (EP) curve and a number of standard risk
metrics could be derived and used for rational quantification and management of the disaster risk to agriculture. Figure 5 shows an example of the EP curve, the average annual loss (AAL), and the loss for a given return period (LossRP). EP curves and derived risk metrics could be conveniently developed at various resolutions – by country regions, by producer type, by crops, etc. as per the needs of the stakeholders. Another consideration for modeling will be the timing of the disaster relative to the agricultural calendar, according to whether crops have already been planted and their maturity leading up to harvest.

3.5. AgriCat Modeling vs. Agricultural Insurance Pricing Models

It is appropriate to address the relationship between existing models and pricing tools for agricultural insurance and the proposed AgriCat modeling. There have been various studies, pilots, and publications articulating insurance solutions for agricultural risk in low income countries – incorporating weather based indices, yield based indices, or some combination of the two. These are all crop loss models outputting deviations from the expected yields and agricultural production. Crop loss mechanisms are focused around providing index insurance for production volatility, principally related to the weather, with products designed to offer support in the range of 5-20 year return period impacts. This modeling is not event based, but explores the probabilities of achieving some index value, based on the analysis of past meteorological observations and reported yield statistics. The outputs of such models are employed by insurers and reinsurers for seasonal pricing of the risk and include technical premiums (average annual loss) for specific types of insurance contracts as well as statistically based PML’s (or return period losses).

AgriCat modeling framework covers the entire range of return periods, and provides event based tail catastrophe losses from extreme events associated with significant damage and disruption to the entire agricultural enterprise including insurance. Development of the proposed agricultural catastrophe loss modeling capability would be necessary to assist the governments in finding full solution to holistic agricultural risk management, for which insurance could provide one part of the solution. In principle the standard crop insurance (which needs improvements) could remain as the “frequency cover” for agricultural incomes, combined and supplemented with catastrophic loss insurance arrangement by the governments to ensure quick disbursement of funds to assist and protect the livelihood of the farmers after a disaster. Figure 6 visualizes the relationship between modeling for agricultural insurance pricing and the proposed AgriCat modeling framework.

4. Observations and Conclusions

Until now agricultural risk modeling has been narrowly focused on crop modeling and yields variability, mostly for the purposes of pricing insurance / reinsurance contracts (annual or for a growing season) in countries where governments provide significant premium subsidies. In these models the tail risk metrics used do not reflect the underlying physical relationships or loss causing mechanisms – they are purely statistical and cannot rationally cover the “tail” extremes. This in turns has an impact on the transparency of the conversations related to tail risk between entities ceding the risk and entities taking the risk.
In this paper we have focused on AgriCat risk modeling, covering losses in assets and production across the entire agricultural enterprise. We have considered the outputs of the proposed modeling framework and their relevance and possible linkages with macroeconomic and agricultural economic models. The countries in which this approach is likely to be most impactful lie at the intersection of significant catastrophes with regions where high proportions of economic activity and livelihoods are associated with agriculture. While neither India and China is poor (in terms of the size and breadth of their economies) – both have huge numbers of poor farmers with livelihoods at risk, and the proposed concept could be applied there as well.

AgriCat risk modeling framework quantifies the tail risk based on the principles of structured physical risk modeling for property CAT risk, employing the probabilistic event based approach. The procedure is intended to deliver four outputs relevant for the governments’ agricultural enterprise: a) loss of capital stock (barns, equipment, land, etc.) due to the disaster, b) direct loss of income (from crops, livestock, fish etc.) due to the disaster, c) loss of nutrition (i.e. in particular when production is providing nutrition to the producer), and d) indirect loss of future production (in years following the disaster). The outputs from the proposed modeling framework include “functionality restoration time” information – defined as time to replant and grow to maturity the crops (seasonal and permanent), and time to repair and restore functionality of other capital assets (e.g. livestock, warehouses, silos, the land, etc.).

We did not address in detail the issue of the timing of the disaster relative to the agricultural calendar, which impacts the ability to recover the production and the revenues generated from it. Conservatively, this could be addressed by assuming a disaster strike with maximum exposure – e.g. late in the season when key crops are being harvested and are mostly in the fields, and no replanting is possible. In further developments more sophisticated linkages between crop volatility of yields (production) and disaster risk models need to be completed, once the proposed framework for comprehensive disaster risk has been implemented, tested, and used.

An essential step for developing AgriCat risk model involves building of a comprehensive Exposure Database on a high resolution GIS database that includes all agricultural producers in a country – small holders, cooperatives, independent producers, large producers, etc. This database should capture the principal agricultural assets: agricultural /farm land and infrastructure, agro facilities (buildings and structures), tools and machinery, agricultural products in production (crops and livestock) on the land (in the fields), products in storage and facilities (harvested crops, battery livestock, agro inputs, etc.), as well as people whose livelihood depend on agriculture and whose labor is required to support the agricultural production. The proposed AgriCat modeling framework will be effective if it is applied across the entire agricultural enterprise.

References


International Fund for Agricultural Development – IFAD (2011), Enabling Poor Rural People to Overcome Poverty In Honduras.


Citation