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Use of Catastrophe Risk Models in Assessing Sovereign Food Security for Risk Transfer

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Abstract

This paper discusses how catastrophe crop risk models can be used to assess food security needs at the sovereign level for the purpose of risk transfer. The rationale for a system to evaluate food security needs at the national level is discussed. The role of technology and remote sensing data availability as an enabler of catastrophe crop risk models is discussed followed by a description of the framework of catastrophe crop models for droughts, representing the peril for which catastrophe models have had the most success. The integration of the output of catastrophe crop models with a food security vulnerability assessment model is described next. Recent advances in analytical modeling of various types of shocks in assessing food security are described but the operational use of these analytical models in the development of food security assessment for risk transfer is seen to be limited for now because of the complexity of these analytical models. The food security vulnerability modeling in the African Risk Capacity, ARC, model is then described as showing a practical solution to the complex problem of assessing food security via a model. Lastly, the challenges faced in risk transfer of sovereign food security risks are discussed.

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Use of Catastrophe Risk Models in Assessing Sovereign Food Security for Risk Transfer[1]

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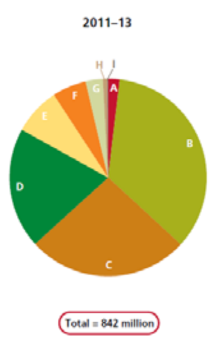
A Nation's Responsibility for Guaranteeing Food Security to Its Citizens

The right to adequate availability of food for all people is enshrined in Article 25 of the Universal Declaration of Human Rights[4] signed by General Assembly res. 217A (III), on 10 December 1948. This was further expanded as a responsibility of each government for providing access to adequate food in Article 11 of the International Covenant on Economic, Social and Cultural Rights (1966)[5]. In September 1996 heads of states and high level representatives of over 100 countries met in Rome, Italy, for the World Food Summit and committed themselves to reducing hunger by half from its current level by 2015 (FAO 1998). This commitment was re-affirmed in the United Nations Millennium Development Goals in the year 2000 to reduce the number of people in poverty and the number of people suffering from hunger by half by 2015 (UN 2000).

Over the last decade, poverty goals were met globally and specifically in developing countries, as well, on the back of general economic development which lifted many people out of poverty (e.g., China). However, the hunger goals have yet to be reached and are considered achievable by 2015 only with a concerted action by national governments and international partners (UN 2013). And yet even with the reduction that has been achieved in the percentage of the global population suffering from hunger from its 1995 level, there are still globally 842 million suffering from hunger of which 98% live in developing countries (see Figure 1). The highest concentrations of people suffering from hunger are found in Sub-Saharan Africa (SSA) and South Asia (SA), as seen in Figure 1 (FAO, IFAD and WFP 2013).

In addition to agreeing to meet poverty and hunger targets by 2015, nations unanimously endorsed access to adequate food as a human right when the FAO council adopted the *Right to Food Guidelines*[6] in 2004 as per the General Comment 12 by the Committee on Economic, Social and Cultural Rights (CESCR) in 1999, which explicitly defined access to adequate food. Additional details on the right to food and obligations of states and international agencies are discussed in the *Report of the Special Rapporteur on the right to food*[7] submitted to the United Nations Human Rights Council in 2008.



	Number (millions)		Regional share (%)	
	1990–92	2011–13	1990–92	2011–13
A Developed regions	20	16	2	2
B Southern Asia	314	295	31	35
C Sub-Saharan Africa	173	223	17	26
D Eastern Asia	279	167	27	20
E South-Eastern Asia	140	65	14	8
F Latin America and the Caribbean	66	47	6	6
G Western Asia and Northern Africa	13	24	1	3
H Caucasus and Central Asia	10	6	1	1
I Oceania	1	1	0	0
Total	1 015	842	100	100

Figure 1. Regional Distribution of Hunger in the World (Source: FAO, IFAD and WFP 2013)

Many nations, especially those with histories of food insecurity, have responded by formulating national food security policies, for example Kenya's National Food and Nutrition Security Policy[8]. Also, there are regional efforts at reducing food insecurity as in for instance the Nairobi Joint

[4] Available at http://www.un.org/en/documents/udhr/.
[5] Available at http://www.ohchr.org/EN/ProfessionalInterest/Pages/CESCR.aspx.
[6] Available at http://www.fao.org/docrep/009/y7937e/y7937e00.htm.
[7] Available at http://www.righttofood.org/wp-content/uploads/2012/09/AHRC75.pdf.
[8] Available at http://www.kilimo.go.ke/kilimo_docs/pdf/National_Food_and_Nutrition_Security_Policy.pdf.

Declaration[9] by countries in East Africa, the region most affected by drought famines, in September 2011 to enhance regional and international partnership to end drought emergencies in the Horn of Africa[10]. In order for a country to ensure the food security of its citizens, it is imperative for the country to develop its capacity to estimate its food needs from its own production, inventories and if necessary from imports and international food aid. However, ensuring food security is a complex task in assessing in real time the quantity of agriculture production in order to maintain an adequate national level inventory to supplement agricultural production to meet the country's food need at times when there is a shortfall in production.

However, food security is not just about availability of food. The other aspects of food security (FAO 2008) are accessibility (is the food economically and physically accessible?), utilization (how safely is the food used to meet the nutrition requirements?) and stability (how are the long-term trends in each of the three factors?). Therefore, it is only by assessing accessibility, utilization and stability in addition to food availability that food security can be evaluated. International organizations recognize the difficulty in assessing food security and attempt to present food security through a suite of indicators of food security status and levels (FAO, IFAD and WFP 2012). These indicators provide in-depth measures of food security when data, time and skilled analysts are available. However, for a developing country the task of estimating its food needs and food security level from the effects of an imminent/ongoing climatic disaster such as a severe drought, using a detailed analysis of all four dimensions of food security is simply not possible because of technological and resource considerations[11]. At the same time solid progress has been achieved in the development of early warning systems (EWS) by international agencies to assess food security at the national and regional levels arising from climatic-induced food production shocks. A number of EWS operated by various international organizations that cover large regions of the world, including the SSA and SA, are the USAID's Famine Early Warning Systems Network, FEWS NET[12], the FAO's Global Information and Early Warning System, GIEWS, the WFP's Emergency Food Security Assessment, EFSA, and Vulnerability Assessment and Mapping, VAM, and the JRC's MARS. Besides these international efforts, there are regional EWS as for instance CLISS, SADC and IGAD in Africa (FAO 2006).

In general EWS of food security are scenario driven assessments of an ongoing event, as for instance an ongoing drought,[13] and the analysis is driven by shocks, be these production or price shocks, as for example the expected yield shortfall from an ongoing drought condition and the anticipated rise in food prices. Therefore, EWS attempt to portray the food security as a snapshot in time. However, if a country wants to understand its food security profile, or in other words the frequency and

[9] The Nairobi Joint Declaration can be downloaded at http://www.statehousekenya.go.ke/speeches/kibaki/sept2011/NBI_DECLARATION_2011090902.pdf.

[10] The Nairobi Joint Declaration was made by Heads of State of countries who are members of the Intergovernmental Authority on Development (IGAD). Present members of IGAD are Djibouti, Eritrea (temporarily suspended), Ethiopia, Somalia, Sudan, South Sudan, Kenya and Uganda.

[11] In addition, there is the issue of how worthwhile given other more pressing needs when there is an actual food emergency?

[12] FEWS NET data can be accessed at http://fews.net/, WFP's EFSA and VAM at http://www.wfp.org/content/emergency-food-security-assessment-handbook, http://www.wfp.org/food-security, FAO's GIEWS at http://www.fao.org/Giews/english/index.htm, and JRC's MARS at http://mars.jrc.ec.europa.eu/.

[13] However, even this analysis need not be a deterministic analysis as the expected shortfall itself can be described probabilistically to give probabilistic assessments of impending food security.

severity of its food security situation, the assessment will have to be undertaken in a probabilistic manner as food production, food prices, and livelihood coping strategies of people when faced with inadequate access of food are themselves uncertain. For instance, food production in countries that practice rainfed agriculture is heavily dependent on the rainfall in the growing season but there is a large annual variability in the rainfall that cannot be predicted beforehand. Market prices likewise are uncertain and predicting the local market prices of agricultural commodities even in the simple context of a regional or national production shortfall has proven to be a difficult task (WFP 2011). Further, the globalization of trade in soft commodities makes the determination of links between global and local prices a highly complex issue (Prakash 2011) that involves market risk, currency risk and government sanctions in addition to climate shocks.

In the following sections, models of crop production losses using a catastrophe risk framework will be presented to show how these models can inform a food security vulnerability model in order to evaluate the food security profile of a nation.

<u>Developing Country Food Security Issues That Are Relevant for Modeling</u>

Agriculture production in developing countries is characterized by its small size farm structure with often more than 70% of the farms being less than 2 hectares in size compared to 15% for developed countries (Adamopoulos and Restuccia 2011). Small scale farmers in developing countries operate at subsistence levels due to the lack of agriculture infrastructure, efficient supply chains, finance and trading platforms. Developing countries often have a high share of rural population, a high share of agriculture in employment and a high share of agriculture in the country's gross domestic product (Mahul & Stutley 2010). Developing countries generally show higher poverty rates in rural areas than in urban areas (World Bank 2014). In some developing countries the rural poverty rate is multiples of the urban poverty rate, for instance in Cameroon the rural poverty rate is 4.5 times the urban poverty rate, 3.3 times in Malawi and 1.8 times in Nepal (World Bank 2014). In SSA and SA countries with their rural share of the total population higher than the urban share and higher rural poverty rates than urban poverty rates, poverty is concentrated more in rural areas than in urban. The rural poor have limited coping strategies as they are already at the limit of their livelihood and in the absence of government support in a disaster farmers are forced to give up farming, sell all livestock and move to urban centers to seek work, which in return can lead to illegal settlements and the development of shantytowns.

Another aspect of agricultural production in SSA and SA countries is the very high dependence on rainfed agriculture, the lack of irrigation systems and overgrazed rangeland from livestock, which means that crop production or livestock mortality is highly influenced by rainfall variability, be it in lack of rainfall (drought) or excess rainfall/flood. The frequency and severity of rainfall distribution is therefore closely tied to the food security of poor rural households whose livelihood income is derived largely from farming activities. At the same time, food security is not just about food production alone, more so for poor people who are net buyers of food, irrespective of where they live in rural or urban areas, as in the case of net food buyers food security is more about food access as has been argued by Crush et al. 2012.

Food security is intrinsically a household issue and is about how households cope financially with reduced access to staple food and increasing prices for food in general. In developing countries, two

groups of people that are highly susceptible to food insecurity are (i) the rural poor comprising of subsistence farmers, pastoralists and landless farm laborers, and (ii) the urban poor[14] who spend a large share of their livelihood income in purchasing food (WFP 2009). The rural poor engage in growing crops for subsistence and/or raising livestock and/or on-farm labor in parallel and how much of each activity they partake in is determined by the size of the household and other factors such as household land size, microclimate and the suitability of the land for agricultural activities. In good years, subsistence farmers might sell the surplus harvest in the local market; however, in years with disasters, such farmers are not producing enough for their own consumption and are not able to supply staple foods in the local market, which could result in local price hikes of these food items. The impacts of drought on the rural and urban poor and the main vulnerability characteristics of these groups are shown in Table 1.

Food security[15] of people can be impacted in other ways besides production and market shocks, for instance as a result of political turmoil, conflict, government's inability to procure staple foods at high global commodity prices, government policy changes that directly affects consumer price indices, wages, remittance incomes, cost of inputs, and market factors that may or may not be affected by domestic production but impact prices of agricultural inputs and market prices of food at the retail and wholesale levels. Modeling the simultaneous impact of agriculture production shortfalls, market and economic policy on food security is an ongoing research effort and is referred to later in this paper when discussing the integration of production shortfall estimates from catastrophe crop modeling and food security vulnerability modeling.

Group	Impact	Vulnerability characteristic
1. Rural Poor		
a. Subsistence farmer	Income affected by loss of food production Expenditure on food purchase affected by resulting price hike because of reduced supply in local market	Low assets and little to no savings; Ability to cope with production losses or increases in food expenditure very low.
b. Landless labourers	Income affected by reduced demand for on-farm labour Expenditure on food purchase affected by resulting price hike because of reduced supply in local market	Low assets and little to no savings; Ability to cope with loss in on-farm labour income and/or increases in food expenditure very low
c. Pastoralists	Income affected by reduced production and/or mortality of livestock Expenditure on food purchase affected by resulting price hike because of reduced supply in local market	Ability to cope with income losses from livestock losses, mortality and/or reduced yield, and/or increases in food expenditure very low
2. Urban poor	Expenditure on food purchase affected by resulting price hike because of reduced supply in local market	High susceptibility to food price hikes as a large share of their household income is spent on food purchase

Table 1. Impact of Drought on Different Groups of People

[14] This is not to say that other groups of people couldn't be affected. For example the global food crisis of 2007-2008 and 2010-2011 showed that households spending a large portion of their income on foods living in food-deficit countries were among the more vulnerable groups though results vary from country to country. For instance Kiratu et al. 2011, show that in Tanzania the 2007-2008 global food price hike caused an estimated 0.5-1.0% increase in the poverty rate driven mostly by changes in urban poverty and rural poverty was largely insulated from the effects of the global price hikes.

[15] Here the emphasis is on large scale food insecurity and not isolated cases such as food insecurity arising from reduced capacity or death of the breadwinner in the household.

Current science and technology has been an enabling factor in the ability to model production shocks from climatic disasters such as droughts, floods and heat waves, as manifested in the development of various international, regional and national EWS of food security. Production shock models have been used for a number of years in developing crop insurance programs at the micro level (small scale farmers) and at the macro level (government assets), (e.g. Syroka and Nucifora 2010, Gonzalez 2009, Mortgatt et al. 2012). This effort has been facilitated by the availability of spatially dense gridded weather data derived from weather station data at the national level and regional to global remote sensing data. The availability of large spatial coverage of weather data in most parts of the world goes back 30 years and the availability of relatively simple, general and soil-plant-atmosphere based crop growth models for most of the major crop s has made it possible to design insurance programs at the micro and macro levels. A framework similar to that used in natural catastrophe property models is used to simulate weather events that are likely in the future (that go beyond the 30 years of historical data) and crop yield models relate the simulated weather events to crop production shortfalls to generate a probabilistic distribution of yield reductions at various return periods.

There are a number of issues that arise in the use of gridded weather data for crop modeling (Gommes, R. and Kayitakire, F. 2012). Remote sensing (RS) data on weather are first of all not as accurate as data from reliable and accurate ground weather stations and are only available for about 30 years. However, most developing countries have limited ground weather station coverage and the number of consistently reliable and accurate weather stations is even smaller. Therefore, there is an over-reliance on RS data, most of which may not have been groundtruthed. This could lead to considerable uncertainties in spatial and temporal distribution of the intensity of the weather events. In addition, the use of crop models at a grid level would require an averaging of culitvars (i.e. cultivated varieties of crops), environment (i.e. soil and weather) and management (i.e. growing season, use of rainwater and irrigation, use of fertilizers, etc.) which could lead to even higher uncertainties. Therefore, there is a real risk that the use of crop models based on gridded RS data may have imperfect correlation with actual crop production. The imperfect correlation between the estimated and actual crop production is referred to as the basis risk. The goal in crop modeling is to reduce basis risk as much as possible so that the model output and ground measurements are highly correlated (Clarke and Hill 2013). At the national/ regional scale which is of interest in this paper the consensus among researchers is that basis risk is lower as a result of aggregation at the grid level relative to the individual farmer level (Gommes and Kayitakire 2012).

Rationale for Insuring Food Security

The rationale for insurance to small-scale farmers in developing countries is that insurance gives small farmers the capacity to take risks to purchase higher quality inputs (seeds, fertilizers, pesticides/herbicides) and get access to irrigation backed by the safety net which insurance offers in case of catastrophe type of losses. Insurance effectively works as collateral to have access to credit from banks because with the insurance there is a guaranteed payout even in years of low yields. With access to improved input supplies, the farmer is gradually able to build a surplus in good years to survive catastrophe type of years. This rationale of insurance to small scale farmers is very much

present in the work done of IRI (Hellmuth et al. 2009) and the Oxfam America R4 initiative[16], Oxfam America 2013. Weather index insurance schemes based on the use of objective, transparent, weather indices that correlate well[17] with crop yield have been promoted by major development agencies and their partners as a way of surmounting the difficulties of traditional indemnity based insurance for small farmers (World Bank 2011). The use of weather indices as part of a risk management instrument for small farmers is discussed in various publications from these development agencies (e.g. World Bank 2011, IFAD 2011, and FAO: Hellmuth et al. 2009, Hazell et al. 2010 and Smith et al. 2009).

At the national level, the rationale for insurance is in enhancing the state's ability to quickly respond to meet the food needs of its people following the impact of a disaster. Agriculture production in Sub-Saharan Africa and South Asia, the two regions that have the highest exposure to food insecurity, and parts of East Asia and South America as well as the Caribbean, is predominantly small scale and rainfed. Extreme rainfall distributions (drought or flood) happen regularly with occurrence of small losses in large areas or large losses in small pockets on an almost yearly basis. However, every so often the climatic conditions are more severe and cover a larger area leading to large losses over large areas (in a country and even regionally across countries) that lead to food crisis situations at the national/regional level requiring international food aid. Impacts of climate change as currently available from global circulation models show the possibility of a more extreme distribution of rainfall, which could impact the more drought exposed countries further.

At the national level, the impacts of large-scale droughts can be devastating and for some countries as in the case of low-income countries in Sub-Saharan Africa the drought risk is significant even at lower return periods. Figure 2 shows the impact of drought on Malawi's GDP by return period of the drought event. The 1-in-10 year event is seen to have a negative impact of 3.5% and the 1-in-15 year event a negative impact of 7.2% on Malawi's annual GDP.

[16] R4 stands for risk reduction, risk taking, risk transfer, risk reserves.
[17] How well the weather index correlates with crop yield and how well the weather index represents the actual weather conditions at a location which could be at some distance from the station at which the weather data is collected define the basis risk, meaning the difference between the actual risk and the modeled risk.

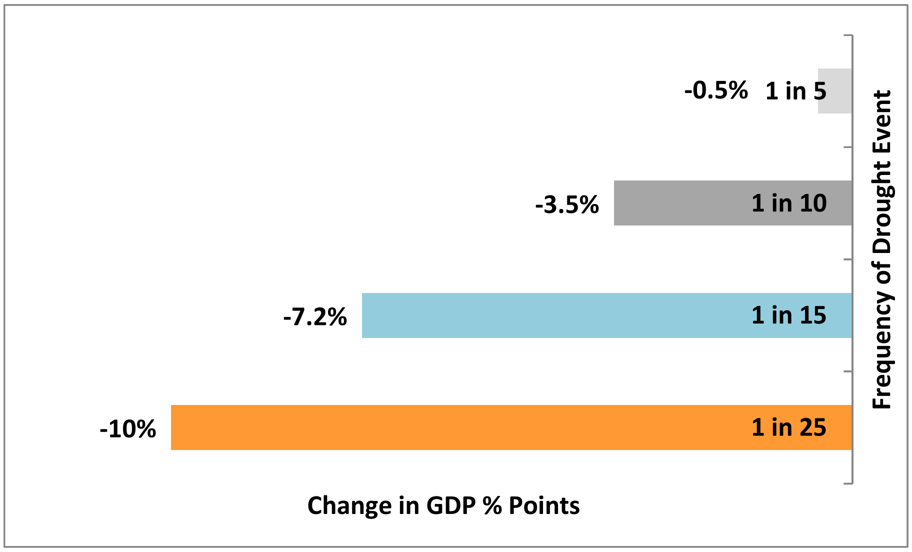


Figure 2. Impact of Drought Events on Malawi's Annual GDP

Source: GFDRR available at
http://www.preventionweb.net/files/15520_gfdrrecon.vulnerabilitydrrmalawimoz.pdf

Figure 2 indicates that Malawi, and other countries with a similar drought risk profile, are highly vulnerable to events that happen on a regular basis. The regularity with which significant reductions in crop production and its adverse macro impact on a nation's GDP occur leads to a vicious cycle of development gains being eroded by drought, and requiring the country to depend on emergency food aid from international agencies. However, even with the best of intentions, international food aid is slow to arrive and the longer the wait is, the worse the longer term impacts of food insecurity are (Clarke and Hill 2013). Therefore, at the national level the rationale for having an insurance scheme is to enhance the state's ability to quickly respond to food crisis situations. For a scheme like this to be meaningful and sustainable the cost of developing such a system and its financial viability need to be assured as has been examined in Clarke & Hill 2013 and from the perspective of the state the premiums should be affordable and the payout should be immediate at times of actual disasters in the future (which implies that basis risk should be low so as not to miss such actual drought disasters). Issues related to sustainability of the insurance scheme, affordability, reliability of insurance being triggered, amount of cover (is it a 1-in-10 year loss or 1-in-25 year loss) above which insurance payout begins and below which the state makes alternative arrangements through other safety net programs, and limits on insurance payments have been extensively investigated in Clarke & Hill 2013 for the African Risk Capacity, ARC, multi-national insurance scheme.

A similar rationale to support governments in the event of a natural disaster to infrastructure was earlier used in the establishment of the Caribbean Catastrophe Risk Insurance Facility in 2007 which pools earthquake and hurricane risks across Caribbean countries (CCRIF 2013). The insurance payout in CCRIF is based on objective model triggers (for earthquakes and hurricanes) that correlate with property losses in each country. CCRIF was initially conceived to insure public infrastructure and the payment if triggered was made to the government to partially offset its infrastructure loss. The

insurance payment while not fully covering the public infrastructure loss provides the government with immediate liquidity to get the government moving on its post-disaster funding.

ARC is developing a similar pooling insurance mechanism for Africa for crop and livestock losses with payouts made to governments to enable quick response to drought disasters as described in *African Risk Capacity (ARC) Briefing Book*[18]. An interesting feature of ARC is that a country wanting to participate in the pool is required to prepare a contingency plan on how the received payout, up to a maximum of USD 30 million (ARC 2012), is to be used in dealing with a food crisis. The insurance and contingency plans are seen as key to improving the capacity of a country to respond to an actual food crises. In addition, there are the additional benefits of enhancing a country's capacity to estimate in an objective manner the staple food needs which is helpful in better positioning the state when it is negotiating food aid from donor agencies for food crisis situations that the state on its own can't handle. In addition, if such a system is coupled with an early warning system capability, as is the case for ARC, a country can start making preparations based on projections of early season rainfall without having to wait for the end of the harvest season.

An affordable national/regional insurance scheme that pays out if trigger conditions are satisfied and whose triggers match the actual crop loss in in future disasters, an early assessment of likely crop yields and food needs, early activation of contingency plans (that are required for participation in the ARC) will together enable a country to respond quickly on the ground at the same time as it starts talks with donor agencies for food aid. A quick response by the government is required if the adverse long-term impacts of food deprivation are to be avoided (Save the Children and Oxfam 2012). If donor agencies make a commitment to devise faster response to a country's food aid requests (Barrett et al. 2001), a country's capacity to respond to food crises could be enhanced, as depicted in Figure 3, so that detrimental long-term impacts of food deprivation are avoided. The credibility of the ARC model is therefore absolutely critical to achieving success in enhancing a country's capacity to handle food crises. First there should always be a payout when there is an actual food crisis (i.e. basis risk should be minimized) and secondly if the early estimates of food shortage are seen to be reasonably accurate then it could form the basis of early negotiation with donor agencies based on the credibility of the model. Further details on how the ARC model can contribute to enhancing food security in Africa is given in the cost-benefit analysis of the ARC (Clark and Hill 2013).

[18] *African Risk Capacity (ARC) Briefing Book* is available at http://www.africanriskcapacity.org/c/document_library/get_file?uuid=9fb04f73-f7c4-47ea-940f-ebe275f55767&groupId=350251.

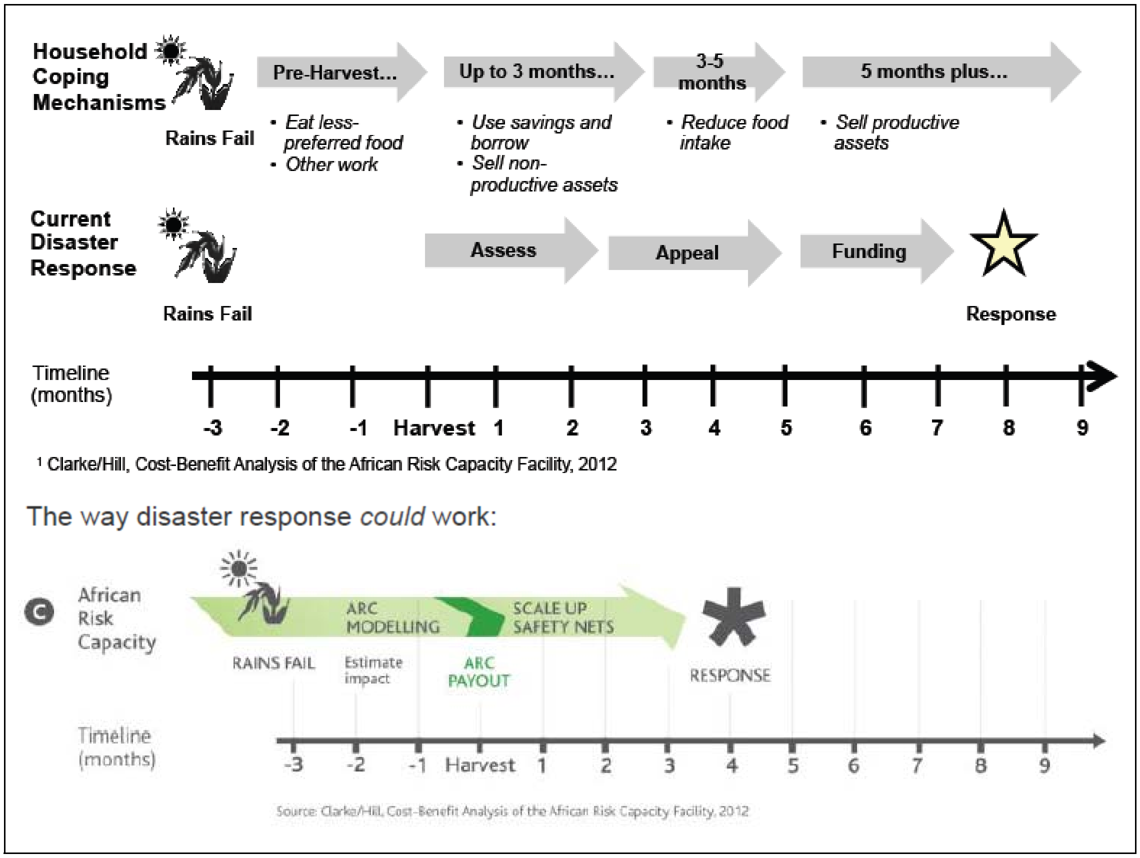


Figure 3. Comparison of Current Food Crisis Response with How Response Could Work in ARC (taken from Syroka et al. 2013)

<u>How can food security at the national level be informed by catastrophe crop modeling?</u>

The availability of large spatial coverage of weather data derived from remote sensing data and weather stations as well as physical crop models for major food staples have made it technically feasible to build catastrophe crop models using a similar framework as used for natural catastrophe property risk models. Modeling crop risk is an exercise in dealing with the uncertainties in modeling the hazard (e.g. drought, excess rainfall, typhoons, heat, frost, etc.) and the uncertainties in the impact of the hazard on crop growth in a manner that is similar to modeling catastrophe property risks[19]. A particular complexity in modeling biological systems (like agriculture) is the dynamics of plant growth and the ability of crops to recover from an impact of a peril depending on the severity and the time of impact. It is therefore only logical to undertake crop modeling in a probabilistic manner using a framework similar to that used in catastrophe property risk models to generate a probabilistic distribution of crop production losses. The output of such a crop model would then feed into a food security vulnerability model to generate probabilistic distribution of a country's food

[19] One major difference between crop modeling and property modeling is the concept of the event. In crop modeling the event is the entire growing season while in property modeling it is typically discrete events as for example an earthquake, flood, cyclone, etc. Therefore, in crop modelling the output is the crop yield at the end of the growing season while in property modelling it is the total losses for each of the discrete events. The other distinguishing feature between crop and property modelling is that the biophysical vulnerability of crops is typically more complex than the physical vulnerability of properties.

security which could be then used in the design of sovereign level food security insurance schemes, as is done for instance in ARC's technical model Africa RiskView[20] used in the design of the insurance pooling.

Catastrophe property models developed in the late 1980s generate probabilistic distributions of property losses for natural perils such as earthquakes and hurricanes (Grossi and Kunreuther 2005). These models which now cover other perils and a wider base of countries have found wide usage in the (re)insurance and capital markets. The catastrophe risk modeling framework is comprised of Hazard, Vulnerability, Exposure and Loss Modules which in the context of sovereign level catastrophe crop models for drought would have the components as described next.

Hazard Module

The hazard module contains a set of gridded values of a drought index that best correlates with crop yield reductions. A common drought index that has found wide usage is the water requirement safety index, WRSI (Senay 2004), which is used in FEWS NET, GIEWS and ARV. There are other drought indices used in other crop models, such as Aquacorp from FAO, EPIC from USDA, CERES and CROPGRP from DSSAT but these models tend to be more complicated and require a large amount of additional data. In the context of developing countries, data required for these models may not always be available and assumptions need to be made in using the more complex crop models thus making them less desirable for operational purposes. In some instances, the Standard Precipitation Index, SPI, which is a simple index based on rainfall data only[21] has been used for drought exposed crop areas with good results but as shown in a recent paper (Legesse and Suryabhagvan 2014) WRSI was a better indicator of agricultural drought than SPI and NDVI[22] (a RS measure of vegetation) in Ethiopia.

Gridded WRSI is generated using gridded estimates of satellite-based rainfall data, soil runoff, soil water holding capacity, potential evapotranspiration (PET) and crop-specific characteristics of cultivated crops (cultivars) such as sowing season, length of growing season, crop growing stages specified by their respective crop coefficients (K_c), crop water requirements and percentage length of growing season. The end of the growing season WRSI is used as the drought index.

The historical gridded RS rainfall data available for 30 years serve as the basis for generating gridded hazard data that could occur in the future. One way future seasonal rainfall data could be generated is to use a bootstrapping technique to combine random sequences of historical dekads (10-day) rainfalls to generate rainfall for the entire growing season (Jayanthi and Husak 2013). A different approach is taken by ARC (Syroka J., personal communication 2014) whereby the 30 years of historical rainfall data were analyzed using principal component analysis, PCA, which is commonly used in analyzing spatio-temporal data, to reduce the dimensionality of the data set. The reduced dimensionality is then used to simulate future seasons for a specified number of years and as each season is equally likely the annual rate of occurrence of a simulated season is the reciprocal of the number of years of simulation. A potential enhancement would be to use rainfall and temperature

[20] As described in the section on introduction and methodology of the ARV available at http://www.africanriskcapacity.org/africa-risk-view/introduction.
[21] SPI is discussed in detail at http://www.wrcc.dri.edu/spi/explanation.html.
[22] NDVI is discussed in detail at http://earthobservatory.nasa.gov/Features/MeasuringVegetation/.

data from Global Circulation models which has the advantage of being more forward looking, including further uncertainties from climate change compared to the PCA which relies purely on historical weather data.

When creating simulated seasons from limited historical data there is always the issue of how well the extreme drought events that could happen in the future are represented in the set of simulated seasons. However, in the case of drought modeling specifically for low resilient SSA and SA countries, as depicted in the case for Malawi in Figure 2, the events of greatest interest are those that happen at return periods of 10 years up to 50 years and droughts events with higher return periods may not be of interest from a practical perspective[23].

Vulnerability Model of Crops to Drought

There are a number of drought indices that have been proposed for monitoring drought (Sivakumar et al. 2011) which integrate information on meteorology, hydrology and agriculture in one index. For the drought index to be operationally effective in assessing food security, it must be simple, generally applicable to many types of crops and be soil-plant-atmosphere based with a high ability to predict yield loss from drought.

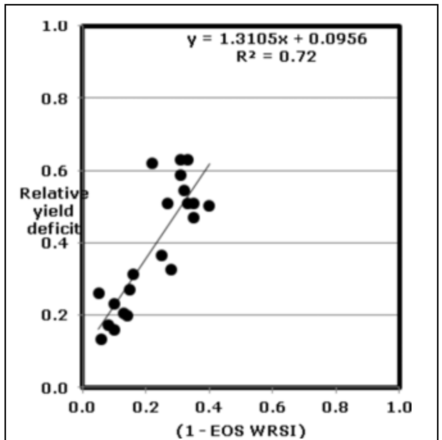


Figure 4. Drought vulnerability model for maize in Malawi

Source: Jayanthi and Husak 2013

In order to model crop vulnerability to drought, the interest is in finding a drought index that correlates best with crop yield reduction. Crop vulnerability to drought is typically expressed by a statistical relationship between a drought index and drought related reduction in crop production in the study areas. These statistical relationships are derived from years for which historical crop area and production data and the drought index for the same area are available for drought and non-drought years. In actual practice the overlap between the production data and drought index may be limited. Issues related to combining crop models with RS data in developing countries with heterogeneous, smallholder farming practices are discussed in the literature (Hoefsloot et al. 2012).

As noted earlier WRSI is widely used, for instance in FEWS NET, GIEWS and ARV and seems to work well in dry places in Africa (Legesse and Suryabhagvan 2014). An example of how WRSI is used is the drought model for maize in Malawi using the end of growing season WRSI shown in Figure 4.There are other drought indices such as the water stress factor, WSPD, used in the DSSAT crop models but these haven't been used as widely as WRSI in developing countries as the information required for the more complex drought indices and their associated crop models may not always be available.

The information that has to be specified for assessing crop vulnerability information is specific to the model and this information needs to be input at the grid level at which the RS data is available. In

[23] This is in sharp contrast to countries with high resilience. As for example the 2012 US drought was the worst drought in 50 years and the highest insured loss in the US since data were collected in the 1980s but the US crop insurance industry was able to absorb it. See Summary of Business Reports and Data of the Risk Management Authority, USDA, available at http://www.rma.usda.gov/data/sob.html.

the case of the WRSI index, data on crop type, start of growing season, length of growing season, soil type, potential evapotranspiration (PET) need to be provided (Senay 2004).

WRSI is currently the most widely used drought index in Africa but a continuing effort has to be undertaken to determine better indices, of course depending on data availability, in understanding the driving factors in yield volatility including rainfall, temperature and other factors such as soil types and irrigation. Ultimately, one could imagine that a multiple index approach where a weight of different indices are used, could work best.

Exposure Module

The Exposure Module captures data on crop type and crop area by region. This type of information is typically collected from a country's Ministry of Agriculture. The government data is typically available at some administrative level, as for instance the district level, and this data is distributed to the grid level using a crop mask that shows percentages of main crops grown in the cell. However, the collected data may not be available for many years and their reliability may be an issue, especially if there are have been shifts in cultivation, multi-cropping is practiced, harvested area differs from sown area, etc. (FAO 2011).

Loss Module

The Loss Module quantifies the crop damage caused by the drought in terms of yield reduction though it could be expressed in monetary loss terms as well if there is an indicative market price for the crop. Yield losses calculated at the grid level are accumulated to sub-national and national levels over grids that lie within sub-national and national boundaries (and may include agro-climatic zones). The yield reduction (or monetary losses for that matter) by event and their annual rate of the simulated events for which can be used to generate the disaster profile at the national and sub-national levels by means of yield shortfall exceedance probability curves or alternately through yield shortfalls at specified return periods (shown in Figure 2).

One issue that's worthwhile re-emphasizing here is that food security in many of the SSA and SA countries is a recurrent phenomenon as can be seen in the disaster data collected by EM-DAT[24]. EM-DAT shows that for many of these countries drought events affecting large numbers of people occur on a regular basis. Therefore, for many of these countries when considering their future drought risks, the period of interest would be events that happen at low return periods, as low as once in 5 or 10 years. A 10-year event for many of these countries with low resilience could be disastrous and the 50-year event could be unthinkable but these may not that significant for another country with higher resilience. A case in point is the 2012 US drought which was the highest insured loss in the US in 30 years since data were collected in the 1980s but the country as a whole and the US crop insurance industry were able to absorb the losses. On the other hand as shown in Figure 2 the 1-in-10 year drought loss in Malawi causes a reduction of 3.5% percentage points in Malawi's annual GDP and would require the Malawi government to request for emergency food aid. Also, as seen in the EM-DAT database, these recurrent droughts affect large number of people and the associated costs

[24] EM DAT is the international disaster database hosted by the Centre for Research in Epidemiology of Disasters (CRED), Belgium. EM-DAT is available at http://www.emdat.be/.

to people and countries are huge as described in the ARC's publication *The Cost of Drought in Africa*[25].

Integrating Output of Catastrophe Crop Modeling into a Food Security Assessment Model

The risk of crop production shortfall can in principle be estimated for all the major staple crops grown in a country as crop models for all major staple crops have been developed. In a similar manner, risk to livestock can be estimated using livestock-mortality vulnerability in place of crop growth models in the Vulnerability Module and a drought index that is appropriate for rangeland. Drought indices used for rangeland monitoring are Rangeland WRSI (Senay et al. 2011) and NDVI (Mude et al. 2009). The estimated probabilistic distributions of crop shortfall and/or livestock losses at national or sub-national levels serve as input to a food security vulnerability model in order to estimate food security needs of a country.

Food security is intrinsically a household livelihood issue and national or sub-national level food security has to start with an assessment of food security at the household level. National or sub-national level food security is then obtained by summing across all households that are assessed to be food insecure. The assessment of food security is not an easy task as assessments of food availability, food accessibility (both economic and physical accessibility), food utilization (nutrition, safety, etc.) and stability (long-term accessibility to safe and nutritious foods) are required at the household level for a complete assessment of food security. The output of catastrophe crop/livestock models only addresses the availability aspect of food security but the other three factors (accessibility, utilization and stability) have to be assessed separately. Various approaches have been taken to assess food security at the household level and for the most part these models are based on an analysis of data collected from field assessments on household income (farm and non-farm sources), household assets (land size, livestock size, savings, etc.) household expenditure (food and other items), and household coping strategies (actions taken to mitigate the impacts of negative shocks) (Seaman et al. 2000). The approaches can be classified broadly into two types (i) Direct use of field data on information on household income, expenditure and coping strategies to identify food insecure households as a result of negative production and/or market (price and/or labor), and (ii) Quantitative models of food security at the household level that have a more analytical framework for accounting that are quantitative and for production shocks, market shocks, and economic and policy shocks.

The first approach is favored by practitioners in the field such as those involved in the WFP's emergency food security assessments, EFSA, (WFP 2009) or the joint FAO and WFP crop and food security assessment missions, CFSAM[26], and in EWS of food security such as the USAID's FEWS NET and FAO's GIEWS. The exact methodologies used in EFSA, FEWS NET and GIEWS to assess food security vary but essentially these rely on estimating the impact on household income and household expenditure resulting from production shortfalls and/or market price hikes to identify households with a food gap. EFSA and CFSAM for instance consider the impacts of (i) production shocks (as estimated from field surveys or crop models), (ii) hikes in food prices and other

[25] *The Cost of Drought in Africa* is available at http://www.africanriskcapacity.org/documents/350251/371107/ARC_Cost_of_Drought_EN.pdf.
[26] The link for CFSAM jointly carried out by the FAO and WFP is http://www.wfp.org/food-security/assessments/crop-food-security-assessment-mission.

agricultural inputs (as estimated from field surveys or obtained from historical price hike data), (iii) changes in on-farm labor market and (iv) changes in other sources of income/food to estimate total impact on income and expenditure. The income and expenditure under shock conditions are compared against those in normal years (referred to as baseline years) and the gap between income and expenditure is combined with information on coping strategies by type of household livelihood group to identify food insecure households. The calculations are done typically in a spreadsheet.

In the second approach, which is more analytical, income-expenditure elasticities are used to estimate changes in expenditure following a change in income arising from a production shock and/or a market shock and/or economic and policy shocks. One such model that is currently being tested in a number of countries is the WFP/FAO's Shock Impact Simulation Model, SISModel, whose structure is shown graphically in Figure 5 (WFP and FAO 2013). As shown in Figure 5, the SISModel takes in as input shocks measured in terms of percentage change from baseline years for each of the three economic and climatic shocks. The model can be run at national level or at sub-national level. The percentage change in crop production and/or livestock losses at either the national or sub-national level are the outputs of catastrophe crop/livestock models, however the market and economic and policy shocks, also, need to be separately provided by manually entering these to SISModel if their impacts are to be incorporated in the estimates of food security. Even if the input shocks were simplified to take into account production shortfalls resulting from a drought and food price hikes and changes in on-farm labor demand, which would happen following a drought, it's not clear how the associated price hikes and changes in labor demand would be specified unless simplified approaches like the one taken in EFSA are employed to use historical price hike data and historical reductions in labor demand following production shocks to estimate price hikes and labor demand changes that could be used as inputs to the SISModel. The subject area of market prices and labor and their role in food security is an ongoing research (WFP 2011). There are a number of market assessment methods (WFP 2013), and both the WFP and FAO regularly monitor agricultural commodity prices globally. Thus while there is a lot of work done on market prices with the FAO publishing *Global Food Price Monitor*[27] and the WFP publishing *The Market Monitor*[28] more work needs to be done to understand the dynamics of production shocks, food prices and labor demand so that these can be input in a food security vulnerability assessment model. In particular, there is a real need to understand the relationship between global food prices traded at major exchanges and local spot market prices to understand the impact on food accessibility at times of production shortfalls.

IFPRI has a model, the International Model for Policy Analysis of Agricultural Commodities and Trade, IMPACT, which carries out multi-commodity, multi-market analysis of demand, supply, and prices for 114 geopolitical regions of the world linked by international trade (Rosegrant et al. 2012). IMPACT even estimates the number of people at risk from hunger but it is based on the use of an adapted version of an empirical relationship between the share of malnourished within the total population and the relative availability of food (ibid.).

[27] The FAO's Global Food Price Monitor is available at http://www.fao.org/giews/english/gfpm/index.htm.
[28] The WFP's Market Monitor is available at http://www.wfp.org/content/market-monitor.

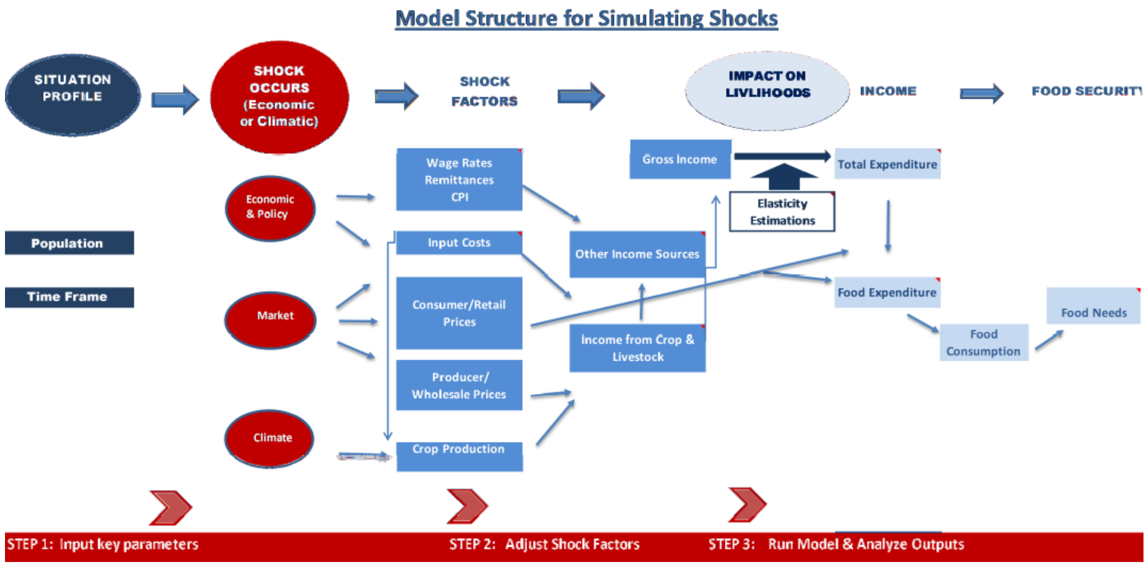


Figure 5. Structure of WFP and FAO Shock Impact Simulation Model (Source: WFP and FAO 2013)

The SISModel was expressly built to analyze the effect of economic and/or climatic shocks on food security at the national or sub-national level while the IMPACT model is a global model designed to examine alternative futures for global food supply, demand, trade, prices, and food security. These models serve their respective purposes for which they were designed but from the perspective of incorporating these models in assessing food security for risk transfer purposes these models, especially the IMPACT model, are too complicated. Simply put, the complexity of these models would make the task of calibrating and validating the food security models risk transfer purposes an almost impossible task as there are too many variables that interact with each other. Of the two models the SISModel is the simpler but as noted above it is not clear how market prices would be assessed in a consistent manner for different levels of production shocks so that their combined effect on food security can be assessed.

Given the difficulty in assessing food security in a consistent manner for operational (as contrast to research) use in food security risk transfer it is clear that some level of simplification will have to be introduced. The goal is to develop a simple procedure that (i) can be applied consistently for all levels of production shocks, (ii) is amenable to calibration and validation using historical data, and (iii) minimizes the basis risk i.e. there is a strong correlation between the estimated number of food insecure people and the actual number of food insecure people in actual drought disasters.

One attempt to devise a practical solution to assessing food security resulting from production shocks is the approach taken in ARV, which is ARC's technical model for assessing food security for the purpose of risk transfer. Box 1 provides an introduction to ARV taken from the ARC's website.

ARV uses a three-step procedure for assessing food insecurity – one in the decision taken to identify the part of the population that has high vulnerability to food security, second in terms of how a production shock is transmitted as a reduction in household income and lastly in defining a threshold level of household income reduction at or above which a household is deemed to be food insecure. In addition, ARV uses another benchmark which is the response cost per person of food

insecurity so that food insecurity costs can be assessed. The three concepts for assessing food insecurity and the response cost are described below.

Box 1. Africa RiskView: Introduction[29]

The first step to establishing a facility such as ARC is understanding — in dollar terms — Africa's drought-related food security risk. As the technical engine of the ARC risk pool, *Africa RiskView* (ARV) is a core product of the ARC Agency. It combines existing operational rainfall-based early warning models on agricultural drought in Africa with data on vulnerable populations to form a standardized approach for estimating food insecurity response costs across the continent — information that is critical for financial preparedness for drought and for providing the basic infrastructure needed to establish and manage a parametric risk pool and trigger early disbursements.

In addition to supporting ARC, ARV provides decision-makers with expected and probable maximum costs of drought-related responses before an agricultural season begins and as the season progresses for every first-level administrative district in every country in Sub-Saharan Africa. In addition to providing a financial early warning tool, identifying and quantifying risk in this objective way can also help countries and their partners direct appropriate drought response actions and target food security investments.

ARV is designed to interpret different types of weather data, such as rainfall estimates, and information about crops, such as soil and cropping calendars. These data are then converted into meaningful indicators for agricultural production and pasture and applied to the vulnerable populations that depend on rainfall for crops and rangeland for their livelihoods. ARV then uses this information to estimate how many people may be directly affected (or have been affected) by drought or deficit rainfall in a given season. Using cost per affected person estimates (see *Methodology*[30]), ARV estimates how much response costs to the observed drought event may be.

Population affected and response cost estimates can be calculated for the African continent, a region, a specific country or part of a country. Users can customize all aspects of the underlying ARV. Countries can also use the tool to select ARC risk transfer parameters to define how much of this modeled drought risk they wish to transfer to the ARC risk pool for each season. See the *How ARC Works*[31] to read more about how these participation parameters are defined.

In addition to supporting ARC, the information produced by ARV has broader applications. It could help to target early food security assessments in specific geographic areas or help with contingency planning and emergency preparedness for future shocks in a country. The tool could also be helpful in guiding planning and investment decisions aimed at enhancing agricultural productivity or market development. To date the tool focuses on drought, but work is ongoing to include flood risk.

ARV is a product that will be offered to countries working with the ARC Agency. It has been designed to be adapted and customized to work within national frameworks, strengthening existing systems and allowing governments and their partners to carry out their own risk analyses, as well as define their own risk management strategy and risk pool participation.

Identification of the Vulnerable Group

ARV considers farming households living in the area affected by the drought with household income at or below the country's poverty line as the vulnerable group.

Reduction in Household Income from Production Shocks

The impact of drought on agricultural income is described by categorizing the intensity of the drought as low, medium and severe. For each of these three drought intensities a percentage drop in the agricultural income is specified. The percentage drop in the agricultural income times the percentage of household income from agriculture (obtained as for instance from household survey data) is used to calculate the percentage reduction in the household income arising from drought.

Threshold Value of Household Income Drop for Defining Food Insecurity

A threshold level of household income drop is defined such that if the percentage drop in household income (calculated above) is equal to or greater than the threshold value then the household is considered to be food insecure.

Response Cost

[29] Available at http://www.africanriskcapacity.org/africa-risk-view/introduction.
[30] Available at http://www.africanriskcapacity.org/africa-risk-view/methodology.
[31] Available at http://www.africanriskcapacity.org/about/how-arc-works.

The response cost of food insecurity per person is taken as $50 per season in areas that are bimodal (two growing seasons) and $100 in unimodal areas (one growing season).

The approach taken by ARV to assess food insecurity is simple and has relatively few variables that can be adjusted to match historical drought losses. The initial settings in ARV based on work by the technical team in charge of developing ARV are meant to be default settings and each country participating in the ARC is given a year to customize these settings[32] (drought categories and their impact on household income, thresholds for determining food insecurity, all parameters related to crop models, etc.) to match their own historical drought losses. This is done with the intention of devising settings at the country level that minimize basis risk for that country with the additional benefit that domestic technical capacity is developed in the participating countries (which is important for the long-term sustainability of the ARC). One thing to note here is that the ARV food insecurity assessments is based on farming households only so this leaves out the urban poor. However, there are scaling factors that each country can specify which can be used for among other things to account in an approximate manner for the other vulnerable people who may not be counted in the current ARV methodology.

One other thing about the current implementation of ARV is that in its first phase of development, the countries about to join the pool have decided to focus on one staple crop[33] they felt was the most important for food security. For example, Kenya chose to look at rangeland in the ASALs[34] and other areas of the country were excluded and Senegal chose groundnuts and the non-groundnut growing areas were excluded from the analysis. What this means is that the scaling factor discussed above which each country customizes is also accounting, albeit in an approximate manner, for the food security of farmers growing crops other than the modeled crop.

The output of the ARV model is an exceedance probability curve of the number of food insecure people and if the response cost is used then then an exceedance probability curve of the cost of food insecurity. A detailed analysis of the basis risk of the current implementation of the ARV is presented in Clarke and Hill 2013. The authors conduct a cost-benefit analysis to examine the financial sustainability of the proposed ARC pooling mechanism and the benefit it offers. In addition, the authors carry out a dynamic financial analysis, DFA, based on which they have made proposals for the amount of cover (in terms of the return period of the drought) that nations should consider buying, the cost of the premium for this cover, etc.

[32] In fact, ARV offers more customization as detailed in *Africa RiskView: Customizaton* available at http://www.africanriskcapacity.org/africa-risk-view/customization. In addition to the settings for assessing drought intensities and their impact on household income, settings on sowing window, length of growing season, soil properties, etc. that impact WRSI calculations can also be customized for each grid.
[33] Personal communication with Dr Joanna Syroka on 20 March 2014.
[34] The ASALs are the arid and semi-arid lands lying mostly in the Rift Valley and they make up more than 80% of Kenya’s land area.

Challenges Faced in Risk Transfer of Food Security Using Catastrophe Crop Models

The challenges faced in catastrophe crop modeling are extensively discussed in a recent publication, (Gommes and Kayitakire 2012). The focus here is on challenges faced in assessing food security for the purpose of risk transfer.

A constant effort needs to be made to improve the RS gridded data. RS data are inherently not as accurate as data from reliable ground weather station data. Many of the international weather data sets are actually the composites of RS data and ground weather station data from different countries collected by the WMO[35]. In many developing countries a more thorough analysis of available ground weather station data needs to be made to look into the possibility of using additional weather station data to get better composites of RS data and ground weather station data. An example of such work is the work done under the auspices of ENACTS Ethiopia (Dinku and Sharoff 2013).

Another improvement in RS gridded data that needs to be explored is the use of higher resolution gridded RS data. EARS, a Dutch consultancy company under a grant from the Netherlands government has developed gridded relative evapotranspiration which is proportional to crop yield, for the entire African continent at 4 km resolution (EARS 2010). The higher resolution data would be obvious significance for devising risk transfer of small-scale farmers however its use for aggregated risks at the grid level needs to be tested against current gridded data that have resolutions of 10 km. The downside to using higher resolution data is the added demand on data storage and data processing and the increase in basis risk compared to aggregate resolutions.

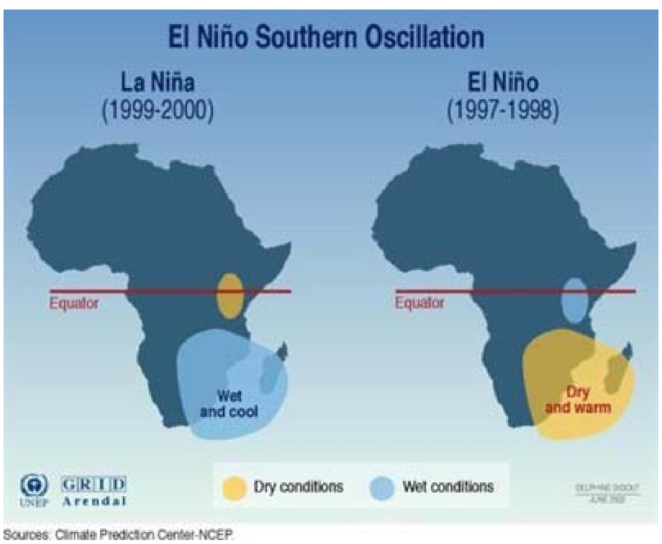


Figure 6. ENSO Impacts in South Africa (Source: UNEP-GRID) available at http://www.grida.no/graphicslib/detail/enso-impact-on-southern-africa_1e73

On the hazard side, there is considerable evidence in the literature on the impact of climate oscillation indices such as the El Nino Southern Oscillation Index, ENSO, which in East Africa is known to have a bimodal impact as shown in Figure 6. As ENSO predictions become more precise given the reliability of EWS there is the potential for anti-selection with nations opting to participate only in certain years. One way to overcome the risk of anti-selection is to enter into multiyear risk transfer transactions.

Besides improving the data on the hazard side data on crop type, crop area, crop yield, soil types and irrigation schemes need to be collected in a consistent and accurate manner, as without these data it is not possible to compare modeled yield with the actual yield. One

[35] See African Rainfall Estimates, RFE 2.0, General Description available at http://www.cpc.ncep.noaa.gov/products/fews/RFE2.0_desc.shtml.

other thing to note is that crop models that have been used so far only take into account the impact of drought and if there were other perils such as those of pests, crop disease, etc., these need to be recorded in the crop yield data if these perils had a significant impact on the actual yield. Yet another issue is intercropping that is quite prevalent in Africa which makes it difficult to establish crop area for the purpose of calculating productivity (yield per unit area). A possible solution for this is to make available a near-real time crop mask.

There is a pressing need to improve the confidence in the methods and tools in order to minimize the basis risk, both the spatial aspect of the hazard and the crop yield aspect. WRSI is a widely used drought index (though less usable for excessive rainfall) but assessments of other drought indices and their associated crop growth models, (e.g. water stress index, WSPD, and the DSSAT crop models) need to be considered to test if gridded crop yield data using other indices and their associated crop models leads to a reduction in basis risk. The key use of the DSSAT model (which shows the highest complexity but also the highest relationship between modeled and actual yields, given all input parameters are available) is to first study which parameters drive and determine yields. The type of evaluation of gridded crop models should of course be done for the developing countries for which food security insurance schemes are being devised taking into account the completeness and quality of data available in these countries. The global proliferation of smart phones makes it possible for crowdsourcing to radically improve the collection of crop data but creating the proper platform for data cleansing, data verification and data mining techniques for processing crop data has yet to happen in the manner that crowdsourcing has now become acceptable in disaster response (Butler 2013).

An operational issue that is related to the use of grids in a world that is typically sub-divided into administrative units is the consistency with which forward and backward mapping between grids used in the crop model and the sub-national administrative boundaries at which populations and crop information are available.

On the food security vulnerability assessment side, it is critical to expand our understanding of drought impacts. A comprehensive way of doing this is through the collection of household data on income, expenditure, assets, food security status, coping strategies. Collecting this type of data is resource-intensive and time-consuming but it is only through such surveys would it be possible to get a better understanding of the impact on drought at the household level and with this better understanding it may just be possible to build simple but robust models for assessing food security.

Data on food aid needs following droughts from field surveys and post-disaster donor cash/food aid should be systematically collected and made available for lookup by type of disaster. Currently, the WFP maintains the DACOTA database[36] that lists the number of beneficiaries of food aid and the UNOCHA has a Financial Tracking Service[37] for tracking global humanitarian aid flows However, unless the information is given by type of disaster, it may be difficult to separate the number of beneficiaries into those that are food insecure because of the drought from those that are chronically food insecure. Getting the number of beneficiaries whose food insecurity is attributable

[36] The DACOTA database is available at http://appsrv01.wfp.org/Dacota/.
[37] UNOCHA's Financial Tracking Service for tracking global humanitarian aid flows is available at http://fts.unocha.org/pageloader.aspx?page=search-reporting_display&showDetails=&CQ=cq090312150914gaMlaOfsXX.

to drought conditions is important in order to facilitate the evaluation of the sovereign level food security model in terms of its bias (over- or under-prediction) and basis risk in estimating the number of food insecure people (Clarke and Hill 2013).

Other considerations that need to be made from an operational perspective are that the model be kept as simple and transparent as possible. As discussed earlier in the context of food security assessments, complex models are also difficult to calibrate either because of the large number of parameters that can be tuned and/or because of the complex nature of their interactions.

Still another consideration is that the model needs to be consistent, meaning that once the parameters are set the model is locked and no further *ad hoc* changes are allowed.

Lastly, domestic technical capacity needs to be built in the developing countries for which the models are built not just to run the models but to enable countries to carry on processing the data and improving the model on their own. In this respect the approach taken by ARC to allow domestic experts in their respective countries to customize the model is promising.

Conclusion

The availability of RS weather data, drought indices and crop models for the major staple crops have made it possible to develop catastrophe crop models. While there are a number of issues that still need to be addressed on the technology side of hazard and crop modeling, mapping of grid to administrative boundaries, etc. the major issue lies in the availability of data on the cultivar, soil type, crop coefficients, etc. at the grid level. The output of catastrophe crop models in the form of a probabilistic distribution of the production shock can be input to a food security vulnerability model to assess the number of food insecure people. Currently, the food security vulnerability model is the weakest link in estimating the number of food insecure people. There is need for more detailed analysis at the household level in actual drought conditions that could lead to simple but robust assessments of food insecurity. The situation in food security modeling today is not very much unlike the early days of catastrophe property modeling when simple, transparent, easy to calibrate and validate methodologies were used, which in the course of time became more analytical and more robust.

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