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The application of a probabilistic catastrophe risk modelling framework to poverty outcomes: General form vulnerability functions relating household poverty outcomes to hazard intensity in Ethiopia

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General form vulnerability functions relating household poverty outcomes to hazard intensity in Ethiopia[1]

We bring together two strands of research that have thus far been developed independently: catastrophe risk modelling, and economic analysis of vulnerability to poverty. We focus on a specific example to fix ideas: the impact of drought hazard on the welfare of rural households in Ethiopia. The aim is to determine the validity of applying a derived set of damage (vulnerability) functions based on realized shocks and household expenditure/consumption outcomes, onto a forward-looking view of drought risk. We outline the contribution that combining the two analyses can bring, show preliminary results and outline future plans.

Probabalistic Catastrophe Risk (CAT Risk) Models have proved invaluable to international insurance markets. They develop a view of risk beyond the historical occurrence of catastrophes, for calculation of potential future impacts. Their strength is that they consider an extensive range of possible event scenarios well beyond the historical record (see Box 1.1). To date, CAT risk models have been primarily developed to output risk in financial terms. However, the potential to use them to support disaster risk management more broadly have been recognized in schemes such as the Pacific Risk Information System[2], CAPRA[3] Program and Africa RiskView platform.[4]

CAT risk modelling frameworks have yet to be applied to poverty outcomes at the household level. Poverty is conceptualized as a level of consumption that is below an "acceptable standard of living". Vulnerability broadens the concept to include the probability that consumption will fall below the poverty threshold (see Hill and Porter, 2014 for a discussion). A growing number of microeconomic studies now link specific stochastic events such as hurricanes, droughts or floods *ex-post*.

CAT risk modelling frameworks comprise models of: 1) Geo-referenced exposure, as assets or population at risk (exposure module); 2) Frequency, severity and location of possible hazard occurrence (hazard module); and 3) The relationship between the modelled hazard occurrence and the impact on the exposure (vulnerability module).

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[1] Very Preliminary Draft for comments, 21st May 2015. Authors: Catherine Porter (Heriot-Watt University) and Emily White, Finance and Markets Department. The project is co-ordinated by Daniel Clarke, Disaster Risk Financing and Insurance Unit, Workd Bank. Please contact authors for latest draft. Correspondence and comments welcome, to Catherine.porter@hw.ac.uk.

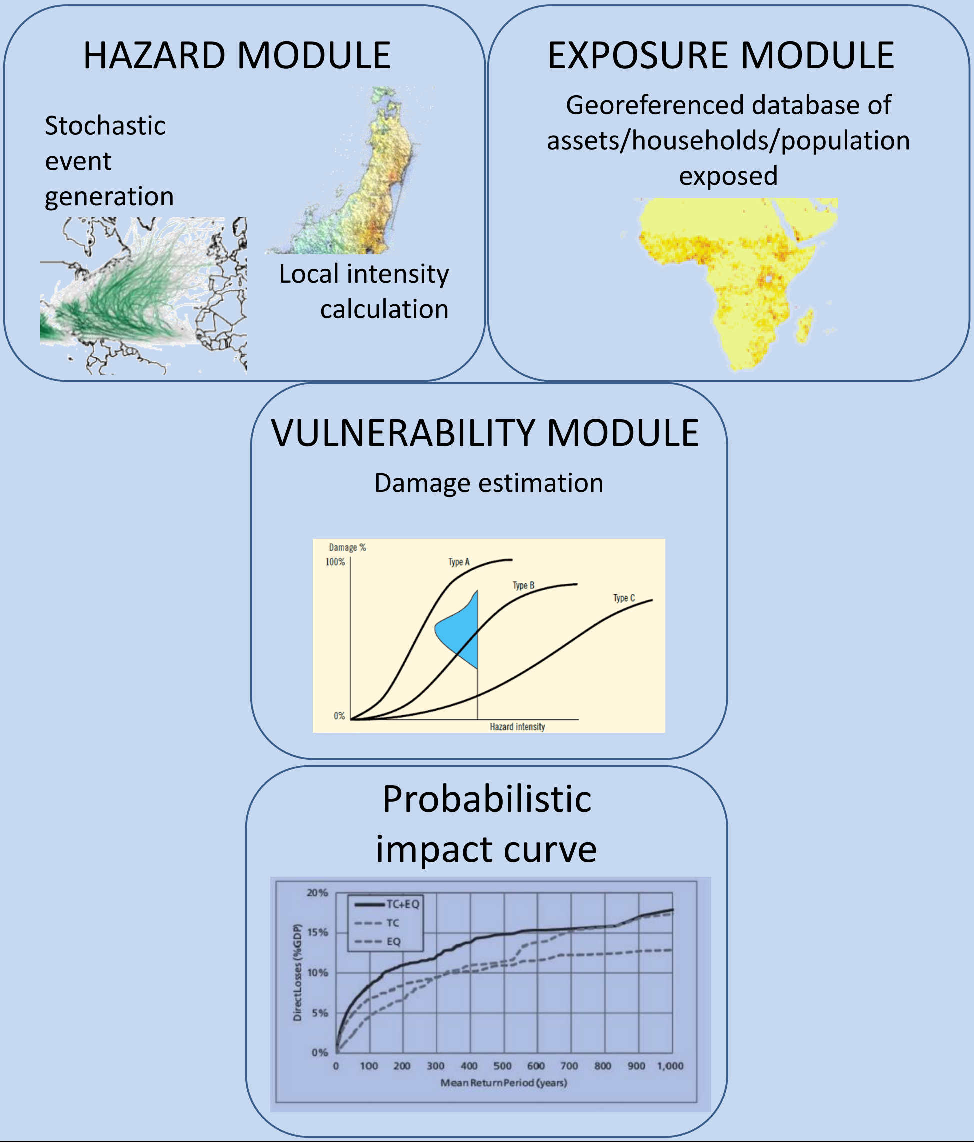
[2] http://pcrafi.sopac.org/about/

[3] http://www.ecapra.org/

[4] http://www.rockefellerfoundation.org/uploads/files/fa08d48b-08ef-4fc7-8991-4872f6e929b0-africa.pdf

This modular structure is illustrated in Box 1.1. **The principal challenge in the application of probabilistic catastrophe risk modelling frameworks to household-level welfare outcomes is the development of general form relationships between hazard occurrence and indicators of welfare outcome (vulnerability module).**

Box 1.1: Probabilistic Catastrophe Risk Modelling Frameworks



To evaluate the feasibility of developing such a module we undertook two activities:

1) **Develop a suitable model to derive quantitative relationships between a selected drought hazard measure and household poverty outcome**. The regression model combines nationally representative household data with historical data on drought hazard, which effectively constitutes our 'vulnerability module' for rural households in Ethiopia;
2) **Testing of the derived 'vulnerability module' to evaluate its robustness**, and therefore the validity of its future application onto a forward-looking probabilistic view of drought occurrence generated from a catastrophe risk modelling framework.

The base **regression specification** is based on initial work by Hill and Porter (2014) that derived a general model of consumption for Ethiopian households using all areas, rural and urban, and focused on the impact of drought, food prices, and other idiosyncratic shocks on ln consumption per adult. The **dependent variable** is the natural logarithm of consumption per adult equivalent at household level, as used by Hill and Porter (2014). The measure of drought is an index of crop yield shortfall (WFP). Other variables include HH head gender, age and education; HH assets including cattle, sheep, chickens, land, good roof, toilet; Idiosyncratic shocks including crop-loss, animal illness or death, hh member illness or death, food price shocks; other characteristics including financial capital and household composition. Community characteristics: agro-climactic zone, region, distance to town, market access.

As noted above, the model also seeks to capture what in CAT risk-modelling are termed attenuating factors, in econometrics as heterogeneous impacts, through interaction terms included in the model (e.g. DROUGHT*varname).

Ensuring that estimates of damage functions are both internally and externally valid is the major econometric challenge in the development of general form damage functions from historical data on disaster impacts. We consider internal validity as the extent to which impacts statistically associated with disaster occurrence can actually be causally stated, i.e., that the estimates are econometrically "well-identified." External validity is considered as the extent to which the model can be generalized to other contexts and locations. CAT Risk modelling allows for the application of the derived functions out of the context in which they were derived. For example, damage functions developed for buildings in one region can be modified for use in another, if sufficient detail around differences in construction types and quality is available.

This out-of-context application is more challenging when considering the impact of hazards on poverty, rather than physical damage, outcomes. The pathway of impact of disasters on household welfare outcomes is complex and involves many indirect mechanisms. The complexity of causal mechanisms demands substantial data to be sure of the validity of the apparent relationships observed in the data. Mechanisms of impact are also influenced by specific factors such as adaptive behaviors that may not be applicable beyond the local context in which they are observed within the data.

The second issue is **over what length of time relationships established can be considered as valid**. For the purpose of CAT risk modelling, it is helpful to consider relationships to be stable over a five-year horizon. We do not deal with the concern of recurrence times and macroeconomic (or second order) effects. E.g. in one crisis households with livestock may sell something in order to protect their consumption, but if another crisis hits soon after, the impact of the second shock is likely to be higher. Finally, in the context of this broader external validity we attempt to check if the specified mode is **valid across Ethiopian agro-climactic zones**.

Summary of results: We do find significantly different impact for households with cattle, access to the PSNP, and financial access: these characteristics are seen to be mitigating the impact of the drought. However, households that suffered other crop damage experienced a heavier impact of the drought. We note the potential concern that financial access and shocks such as crop damage are self-reported.

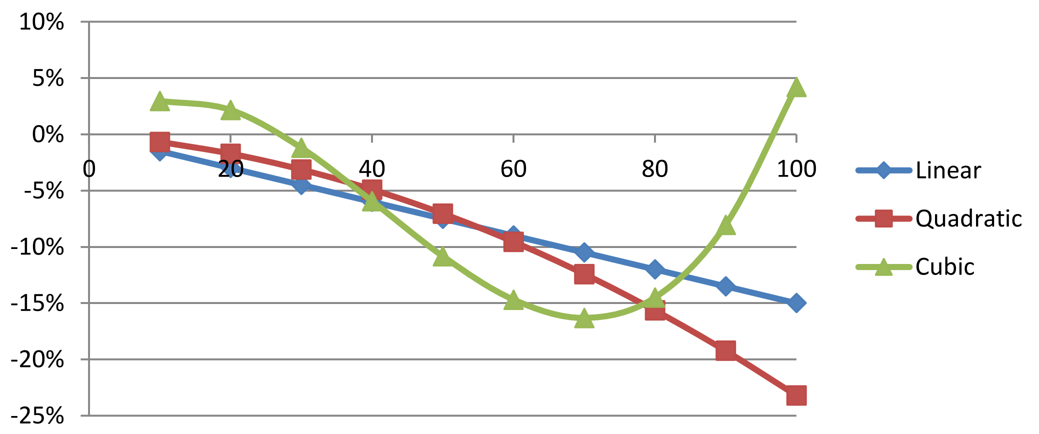
To establish external validity of any statistical results across time and contexts beyond reasonable doubt, it would be necessary to conduct identical analysis many times (replication) and then derive bounds for the relationships. This is not possible in the timeframe of the initial analysis, but has potential for a future exercise, attempting to validate results across as many countries and time periods as data permit.

To test the predictive power of the vulnerability relationships we use Statistical Learning Methods of re-sampling and cross-validation (James et al, 2013). K-fold Cross validation: randomly divide the data into training and testing datasets, and check performance of the model using Mean Squared Error. We also compare the bootstrap estimates of the drought parameter across all models.

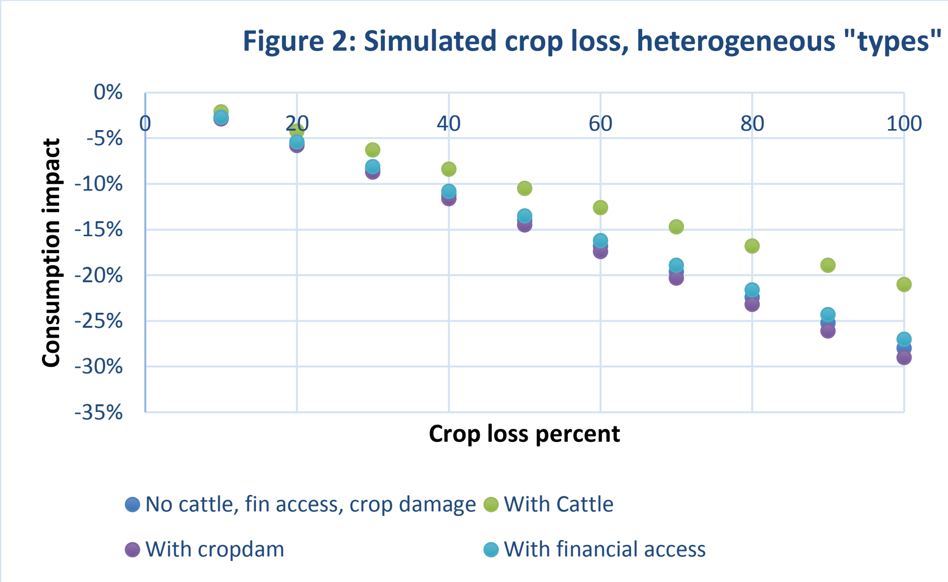
We treated 2005 and 2011 separately as training and testing data. For all the models the 2005 dataset fits the model predicted by the 2011 dataset better than the 2011 dataset fits the model predicted by the 2005. This is a somewhat unexpected result, given that the 2005 dataset has more variation in the rainfall/drought variable. (though note the timing of PSNP safety net introduction in mid-2005). In all cases there is only a small (n.s.) difference in the fit of the model, which suggests that the relationship between drought and consumption is actually fairly homogenous, and stable. **Using 2005 as the training datatset also appears to fit all models better for the 2012 dataset than 2011**, though in all cases the fit is much worse.

Results: Non-linear impacts of drought: Figure 1 shows the simulated shape of the curve using the squared and cubic models. The cubic model appears to have a second turning point around 70% crop loss- which is around the point at which we lose support for the data in 2011, so we may not have enough values of the data to create a plausible estimate for any further nonlinearity than a squared term. This means that the **results for more extreme drought should still be treated with a high level of uncertainty**.

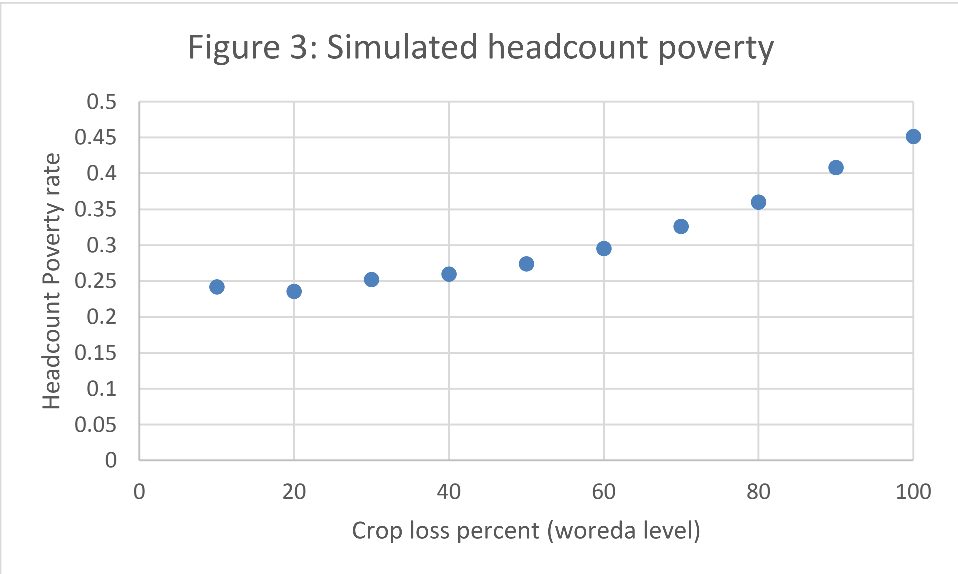
Figure 1 Comparison of non-linear models



In the absence of a probabilistic hazard model for rainfall variability in Ethiopia at the resolution required, we have produced illustrative examples (figure 2):



Finally, if the policy interest is in ***poverty impacts of drought***, then this should be incorporated into the module. E.g. a 20% drop in consumption will push households already below the poverty line into deeper poverty, those well above the line may not fall into poverty but those whose consumption is less than 20% above the poverty line will fall below the line. Figure 3 illustrates with headcount poverty rates, this can also be extended to incorporate poverty gap with associated fiscal costings.



As a potential extension of the exercise, we recommend that a full probabilistic catastrophe risk model be used to replace the example approach applied above for the hazard module. Sensitivity analyses could be applied within the hazard modelling to consider potential outcomes in the longer term under climate change scenarios. For example, increases in the rates of occurrence of extreme rainfall variability could be used to look beyond the near term view. Similarly, projections of population increase and composition change could be applied to the exposure dataset to demonstrate different future outcomes.