# Modelling Macroeconomic Effects of Natural Disaster Risk: A Large Scale Agent Based Modelling Approach Using Copulas

Hochrainer-Stigler, Stefan[1], Poledna, Sebastian[1]

*1IIASA-International Institute for Applied Systems Analysis, Laxenburg, Austria, hochrain@iiasa.ac.at*

**ABSTRACT:** We introduce a copula approach to model dependencies between risks and show how this could be used to avoid underestimation of extreme events in large-scale risk assessments. We apply the approach within an extensive agent based model to determine the macroeconomic consequences due to catastrophic events. The agent based approach is capable of modelling an entire national economy with all sectors, including households, firms and banks. It is based on an input-output model with 64 industries where all goods and services are produced endogenously. We show that without a copula approach only average annual losses on the country level would be available which limits analysis on long term effects. However, with the copula approach, which includes the estimation of basin scale loss distribution through catastrophe modelling, exposure estimation through Corine land cover mapping, assessment of appropriate copulas and parameter estimation, including an algorithm to couple coupled basins as well as an upscaling procedure to the country level, the whole risk spectrum can be estimated. The direct loss estimates from the copula approach, separated into different risk bearers, are used to build a damage scenario generator which gives the input for the agent based model. The agent based model in turn assesses the additional indirect losses due to the event which can be much larger than the direct losses alone. The agent based model is calibrated to the case auf Austria at a scale 1: 10, e.g. with hundreds of thousands of agents and the agents are calibrated according to micro data, including business information, balance-sheets, and income statements. We show that there can be severe effects due to large scale natural disaster events through different transmission channels, even leading to systemic risks. This detailed information should be useful for determining risk management options on various scales.

***Keywords:*** Flood Risk, Copula, Agent Based Modelling, Macroeconomic Effects, Austria

## 1. INTRODUCTION

Macroeconomic modelling of natural disaster events is still a very active research area today. While most of the studies either used empirical or theoretical models for their analysis, so far, no large scale agent based modelling approach was applied for this task yet. However, this may be a very important new modelling approach as different transmission channels could be identified for short or long term effects or even systemic risks. This paper presents an approach which combines an extensive risk assessment of extreme event risks using copulas which is coupled with a large-scale macroeconomic agent based model to determine macroeconomic effects of natural disaster events under a risk based setting.

## 2. FLOOD RISK ESTIMATION

Flood risk estimates in the form of loss distributions from catastrophe modelling approaches are usually only available on the GRID or basin scale and for the estimation of country level risk there is the challenge to up-scale these risks to higher levels. Not until recently, information on flood risk was only available for specific events or expressed in terms of average losses. Consequently, the full probabilistic risk information was not available anymore on these scales and risk management strategies cannot be applied any longer (additionally averages do not give any information about the severity from extremes). We therefore perform a copula-based approach to derive probabilistic flood risk estimates on the country level. In more detail, we apply a structured coupling of probability loss distributions on the basin scale (derived from LISFLOOD) based on a method discussed in Jongman et al. (2014) and more recently in Timonina et al. (2015). The flood loss data on the GRID scale has been validated in previous pan-European studies and provides therefore an ideal entry point for our analysis as we will be able to include climate change effects within one coherent approach. Figure 1 is showing the approach in a nutshell. While only average annual losses can be calculated without a copula approach, the whole risk information is available using a variety of techniques explained further down below.

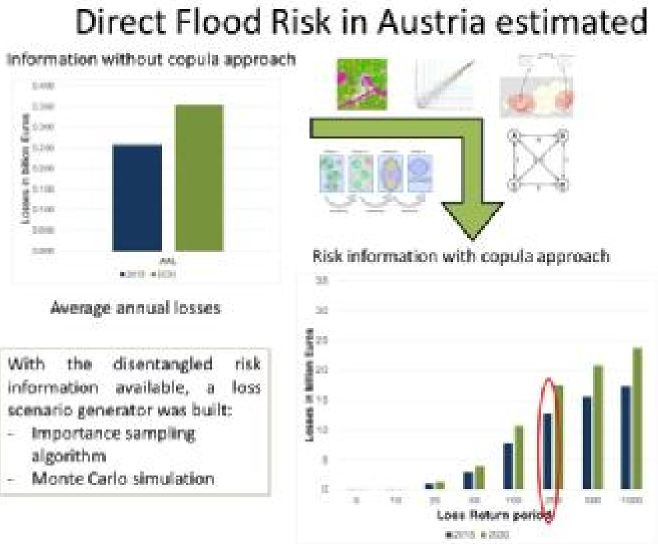


Fig. 1: Flood Risk estimation approach and damage scenario generator for Austria

Dependencies between river basins in Austria are estimated using different copulas (e.g. Clayton, Frank or Gumbel) and are based on maximum river discharges for the period 1990-2011. Afterwards, the loss distributions from each basin are coupled using the given copulas and a minimax ordering approach to finally derive a loss distribution on the country level. The details of the copula methodology, which is now seen as most appropriate to avoid underestimation of extreme risk (see Jongman et al., 2014), and a general algorithm to perform such coupling can be found in Timonina et al. (2015) (Figure 1). To the authors knowledge there is only one other model currently available for Austria using a copula approach. The loss distributions for Austria, derived by the application of the copula approach, form the basic input for the agent based modelling approach. We developed a damage scenario generator using an importance sampling algorithm to generate scenarios over given time horizons, e.g. a no event scenarios, two or more event scenarios etc. For each scenario the corresponding probability can be calculated using the available loss distributions. Furthermore, for each damage event the distribution of losses to the different sectors were determined using the CORINE land cover classes available for all European countries and the HORA zoning system which is available for Austria and gives the probability of flooding on a fine GRID based scale.

### 3. AGENT BASED MODEL

The damage generator gives as input the total losses separated into the 64 different sectors to the agent based model. As Figure 2 indicates the national economy consists of several types of agents, including households, firms, banks and the government. The agent based model in turn assesses the additional indirect losses due to the event which, as indicated here further down below, can be much larger than the direct losses alone. As Figure 2 indicates, total losses can be broadly separated into household losses, losses to the business sectors, as well as losses to the government. Due to the interaction of these agents through various transition channels, e.g. labour reduction, decrease in fiscal revenue or even bank defaults, the long term effects of the disaster can be assessed in detail.

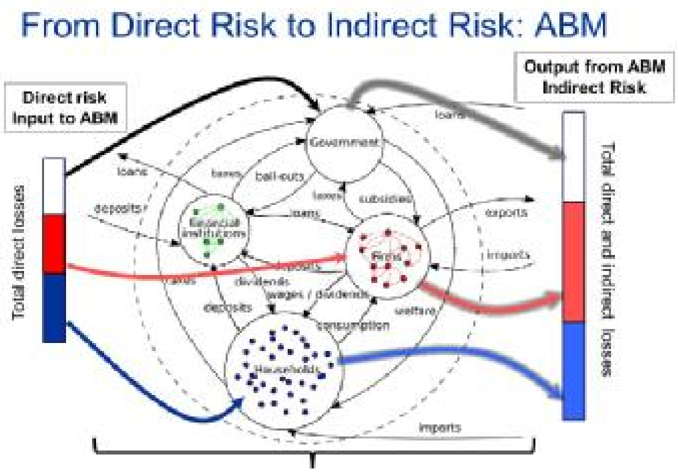


Fig. 2: Input of Flood risk into ABM and calculation of indirect risks

The agent based model employed is based on the CRISIS modelling approach and adapted to our specific needs. Summarizing the main features of the model, it is a stock-flow consistent model of a real and financial economy and models an entire national economy with all sectors (households, firms and banks). Furthermore, it uses an input-output model with 64 industries where all goods and services are endogenously produced. Additionally, there are multiple markets, including Labor, Consumption, Loans, Intermediate goods/services, Bonds, etc. The agent based model itself is a complex network with several supply chains and interbanking and is modeled at a scale 1: 10, which means that hundreds of thousands of agents are acting simultaneously. The agents themselves are calibrated according to various micro data available and include business information, balance-sheets, income statements, to name but a few.

## 4. RESULTS

Using this large scale approach it is possible to analyse various disaster event scenarios in time and space. For example Figure 3 is showing the output of 2 runs, one is the baseline with no events (in green) and the other is showing GDP and government deficit effects due to a disaster event as one of the main macroeconomic performance indicators. The time scale is over a 15 year time horizon.

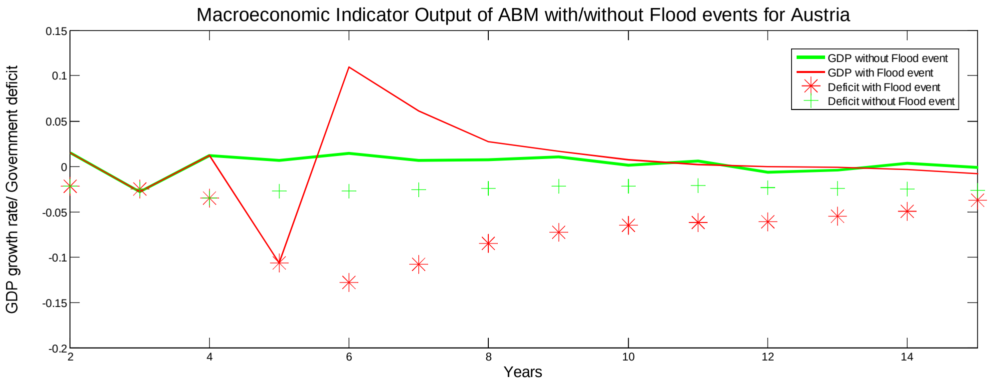


Fig. 3: Output (GDP growth and government deficit) of model runs for flood risk events

Financing of losses may seem to increase GDP growth but actually comes with the price of increased indebtedness which weakens fiscal stability and consequently country credit rating. The ABM is able to give detailed information about the reasons why some disasters may spread through the whole economy and some don't. This is important to appropriately design financial instruments to decrease long term as well as possible systemic risk.

## 5. CONCLUSION

We presented an approach how to estimate extreme event risk on a large scale basis using a copula approach. The method was applied for the case of Austria and it was shown that this disentangled risk information gives better indications of losses due to extreme events. As usually, such events also can cause long term effects, possibly via different transmission channels, and we employed an agent based modelling approach which models the economy of the country at a 1:10 scale to analyse the effects of extremes. Such an approach have not been suggested and performed yet on this scale. The agent based model was calibrated to the Austria case. We found that small disaster losses will not affect the country's economy on the long term, while it can be seriously disrupted for larger or smaller recurrent events, eventually leading to systemic risks under specific circumstances, e.g. if the debt of government is too high and a serious of disaster events hit the country consecutively. Our model approach should be helpful to determine feasible and sustainable long term policy options to avoid such long term effects.

## 6. REFERENCES


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