International Institute for Applied Systems Analysis
I I A S A www.iiasa.ac.at

Multiple Breadbasket Failure Modelling
- systemic risks in the food system -

Franziska Gaupp

and
Michael Obersteiner
Stefan Hochrainer-Stigler
Asjad Naqvi
Juan Carlos Laso Bayas & AgroTutor Team
Tania Ermolieva
Esther Boere
…

International Institute for Applied Systems Analysis (IIASA)

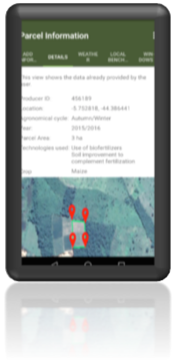
Ecosystems Services and Management (ESM)/
RISK group

May 21, 2019

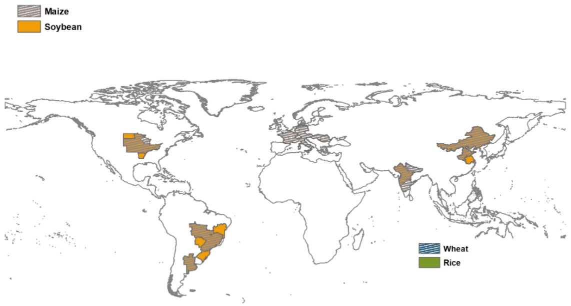
Next-Generation Food Shock Modeling Workshop, Aspen

GLOBIOM

AgroTutor

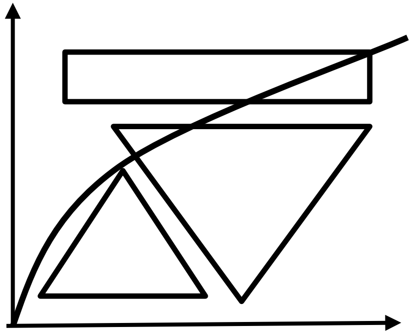


Multiple Breadbasket Failure Initiative

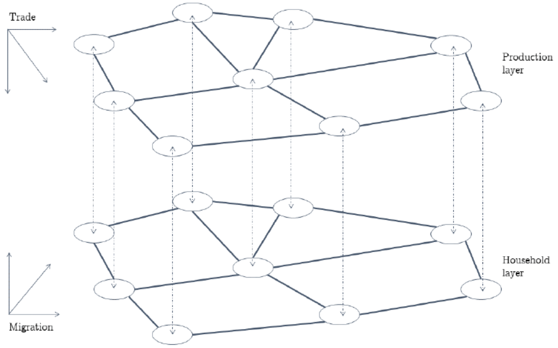


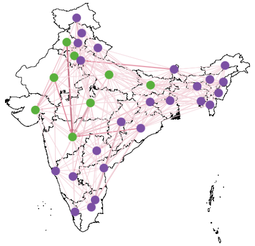
Climate risks in global breadbaskets

CatSIM/ Risk Layering



Networks/Agent-based models





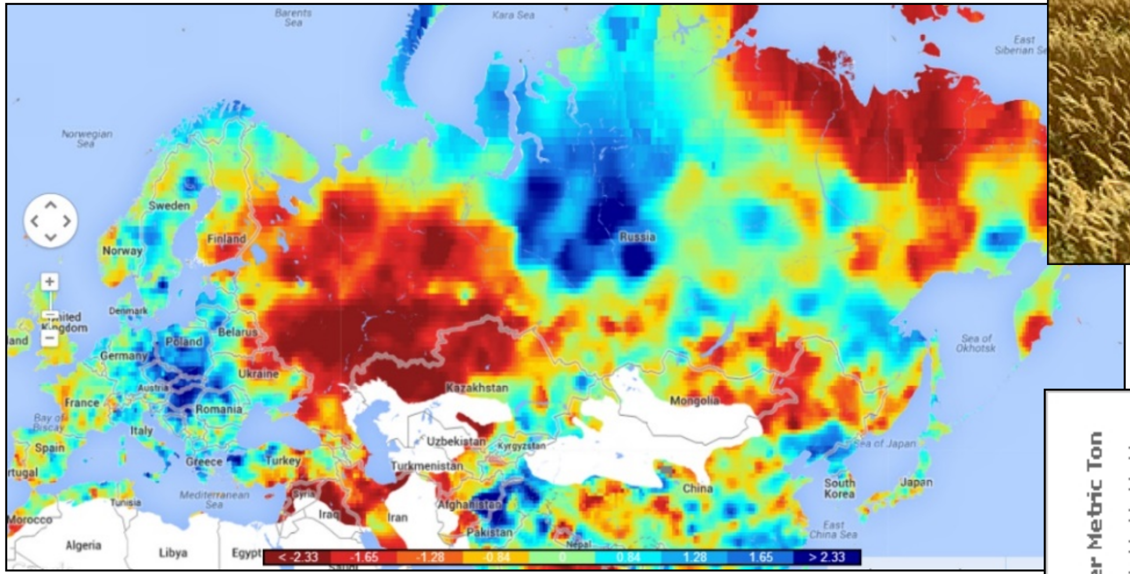
MBBF

Multiple Breadbasket Failure Initiative

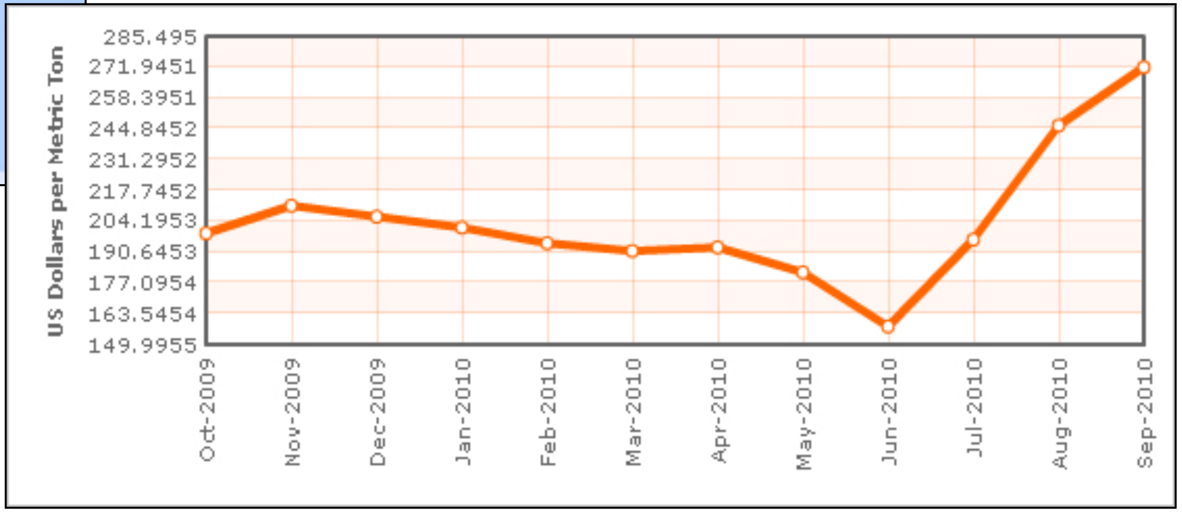
IIASA

Russia, 2010

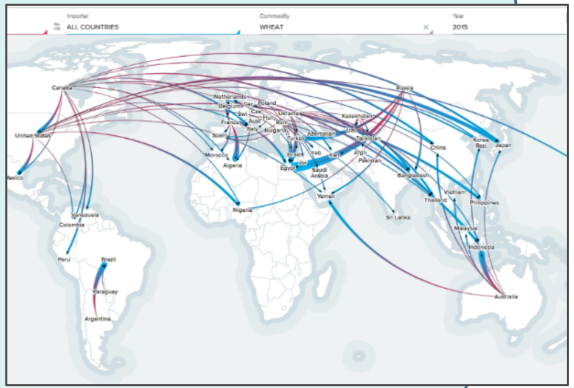
SPEI Global Drought Monitor: October 2010

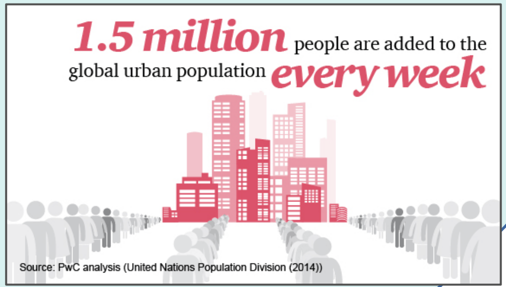


Wheat prices in US Dollars (Worldbank)



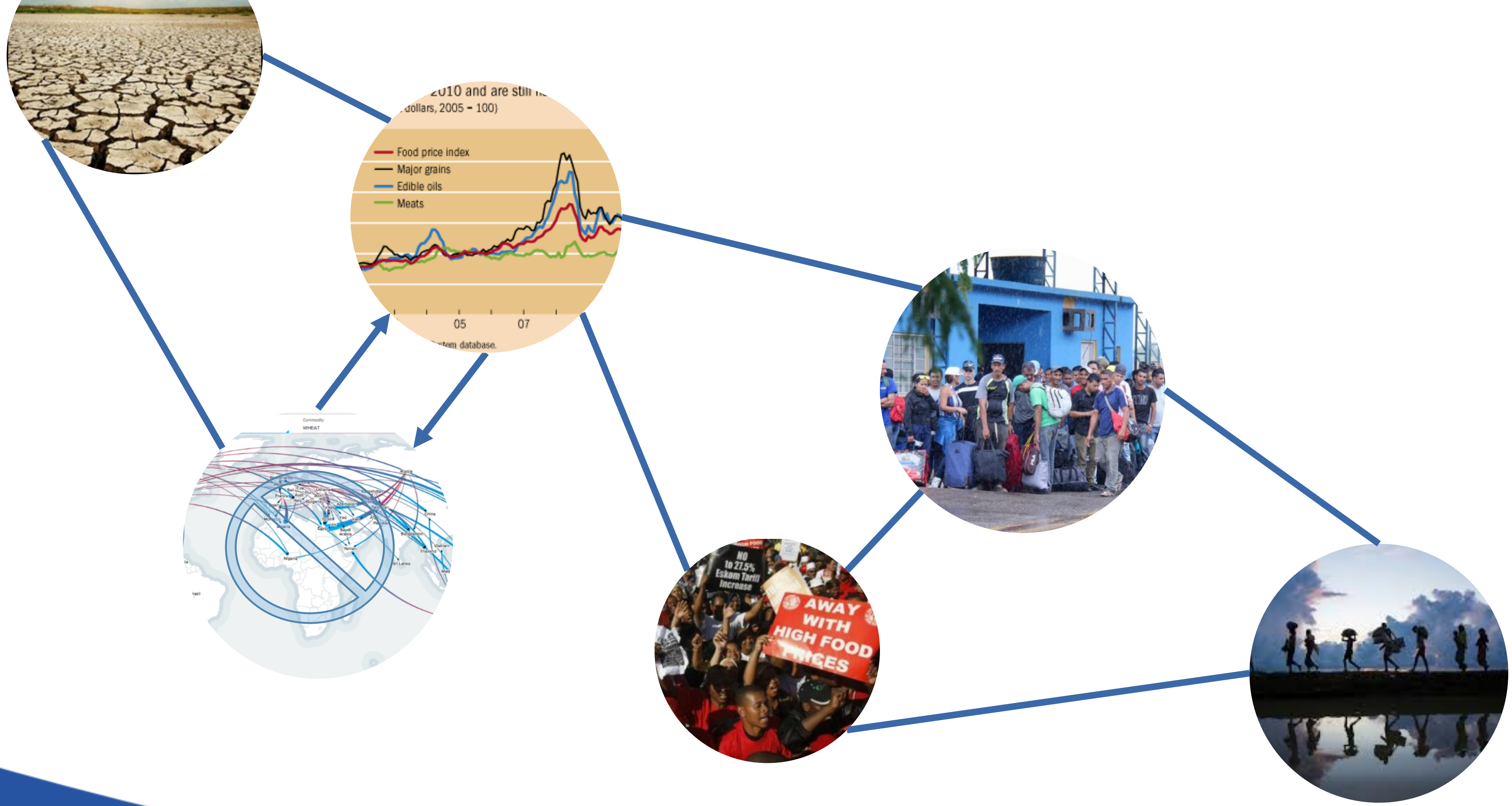
Slow drivers of systemic food system risks

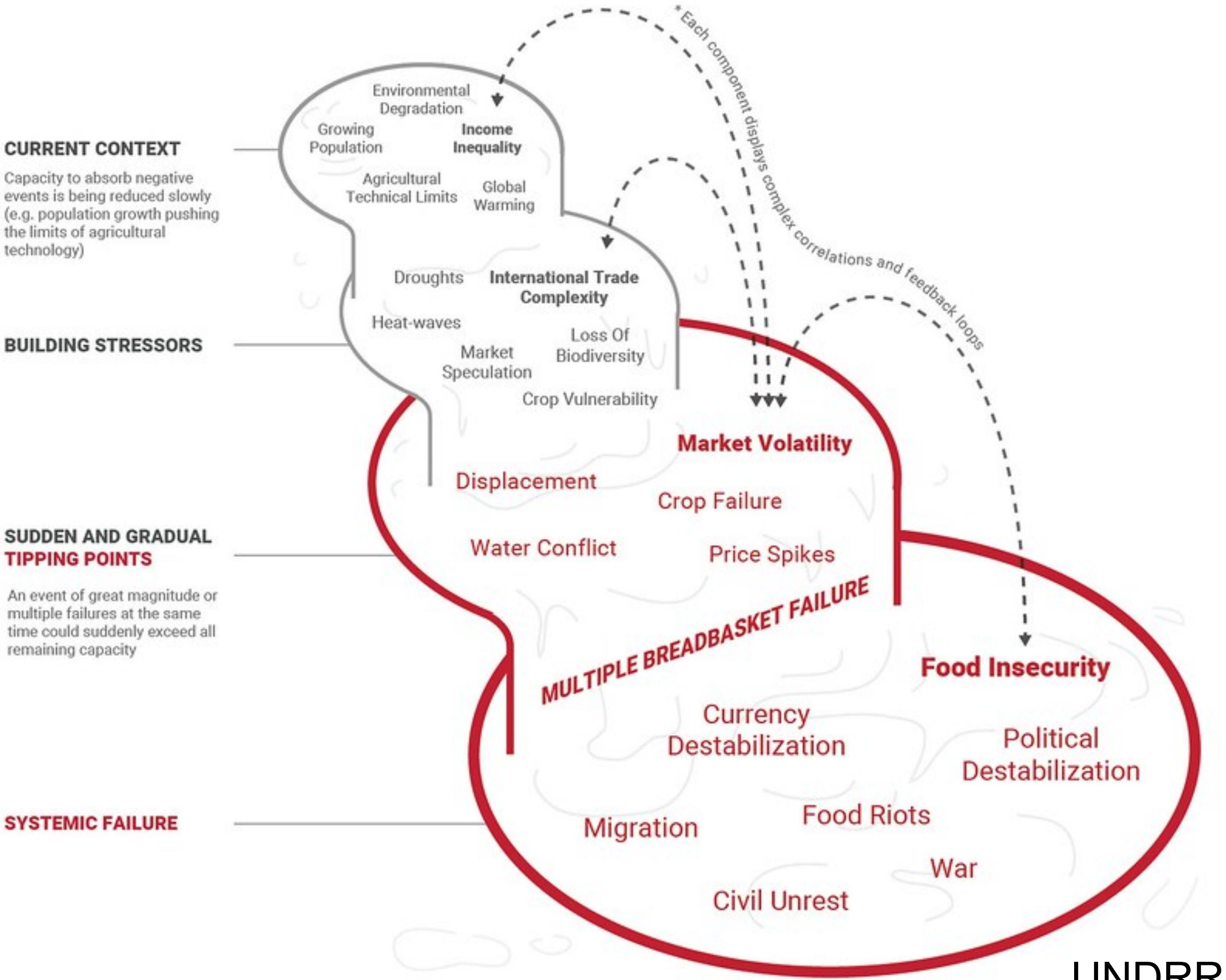




Triggers

Cascading effects



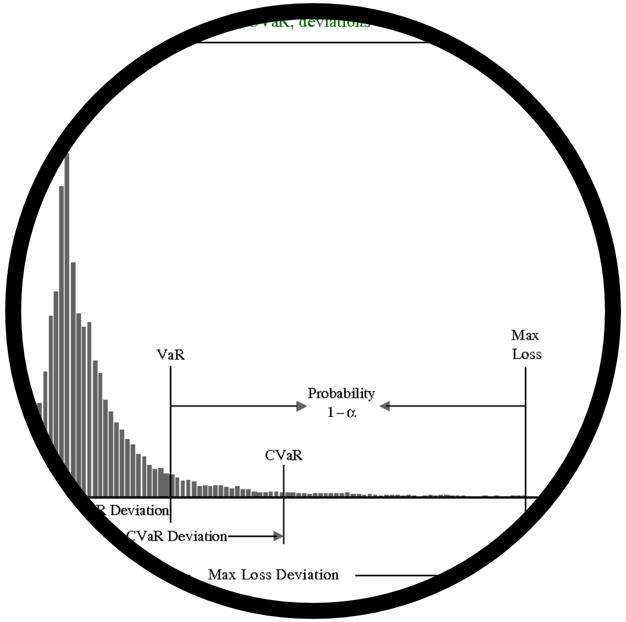


CURRENT CONTEXT
Capacity to absorb negative events is being reduced slowly (e.g. population growth pushing the limits of agricultural technology)
BUILDING STRESSORS
SUDDEN AND GRADUAL TIPPING POINTS
An event of great magnitude or multiple failures at the same time could suddenly exceed all remaining capacity
SYSTEMIC FAILURE
Environmental Degradation
Growing Population
Income Inequality
Agricultural Technical Limits
Global Warming
* Each component displays complex correlations and feedback loops
Droughts
International Trade Complexity
Heat-waves
Loss Of Biodiversity
Market Speculation
Crop Vulnerability
Market Volatility
Displacement
Crop Failure
Water Conflict
Price Spikes
MULTIPLE BREADBASKET FAILURE
Food Insecurity
Currency Destabilization
Political Destabilization
Migration
Food Riots
War
Civil Unrest

UNDRR, GAR19

Pathways to a resilient food system

Data & Technology



Improved Risk Modelling

Complex Systems Thinking

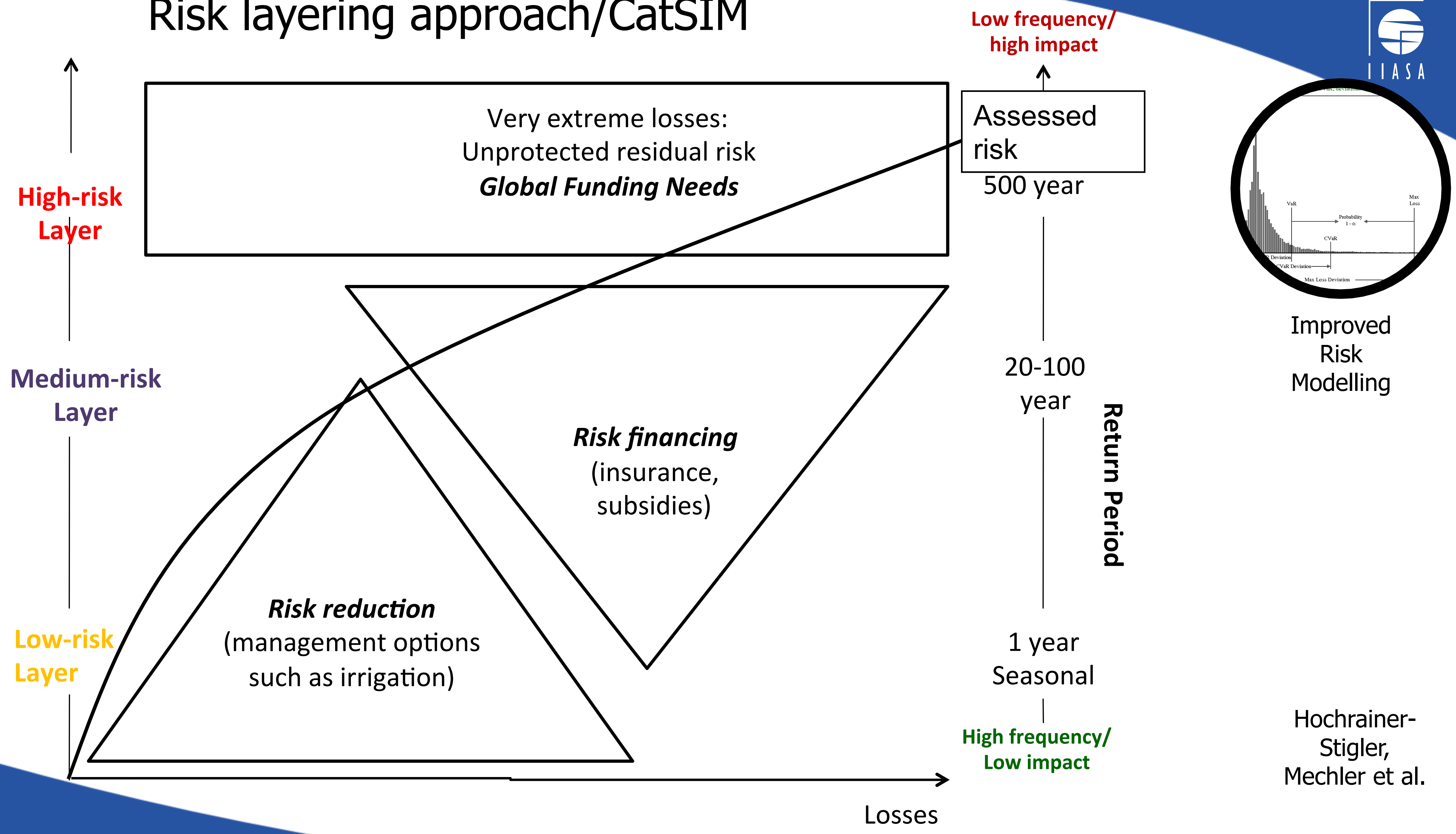
Data & Technology

AgroTutor (IIASA & CYMMIT)

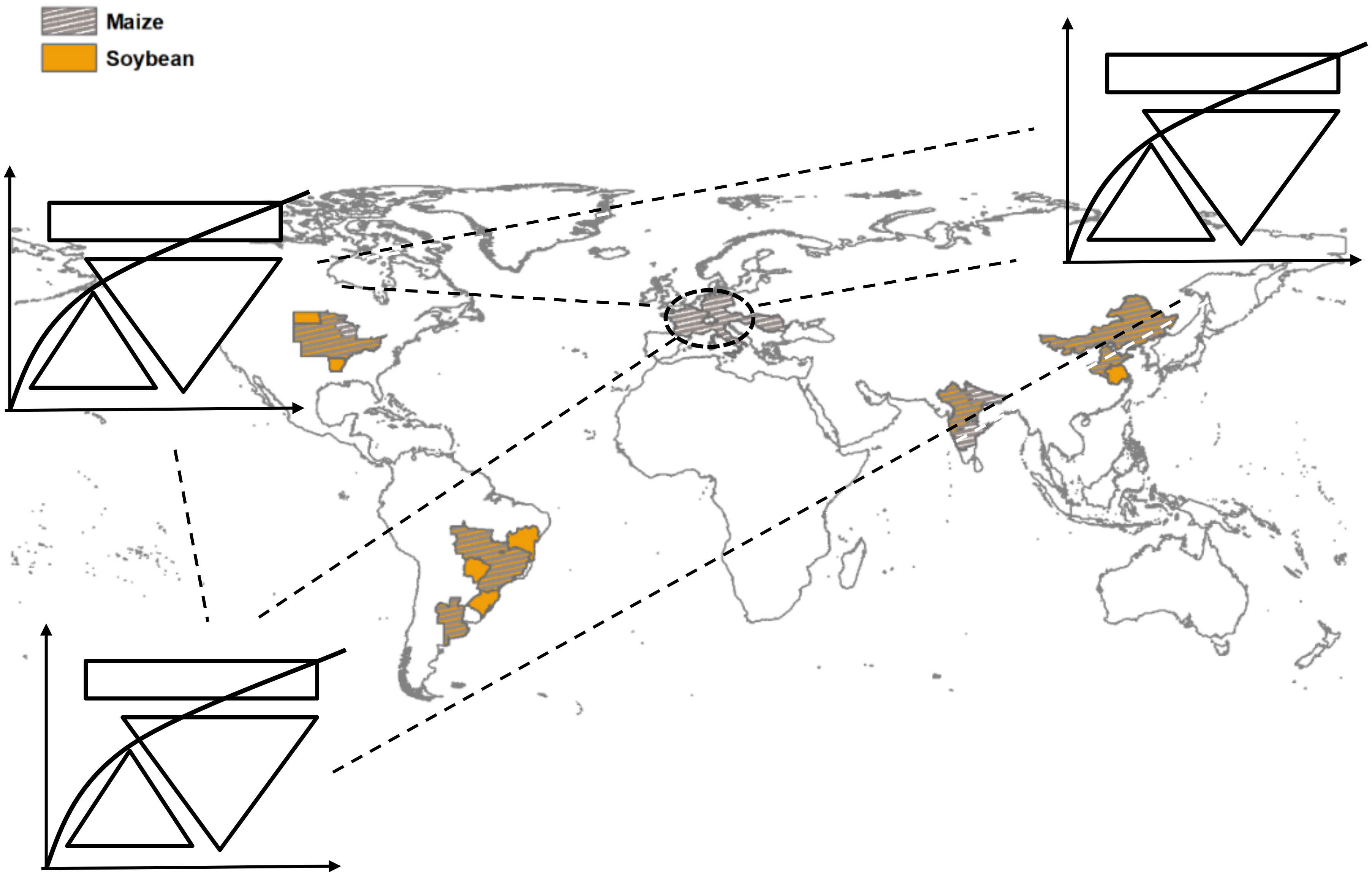
- Yield potential
- Price forecasting tool
- `Windows of opportunity`
- Early warning for pests and droughts

Laso Bayas et al.

Risk layering approach/CatSIM

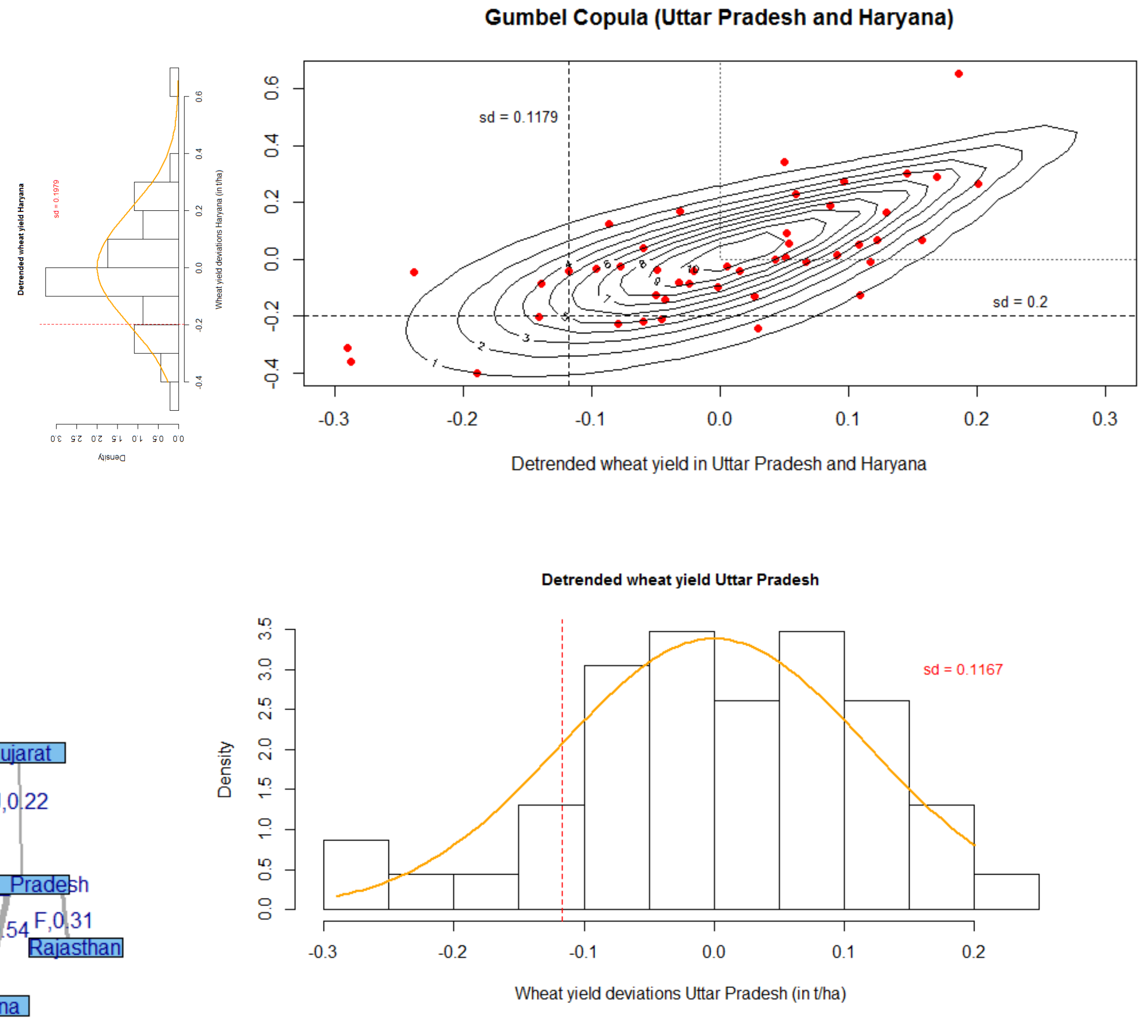


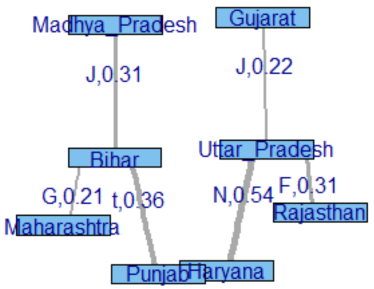
Hochrainer-Stigler, Mechler et al.


Maize
Soybean

Complex Systems Thinking

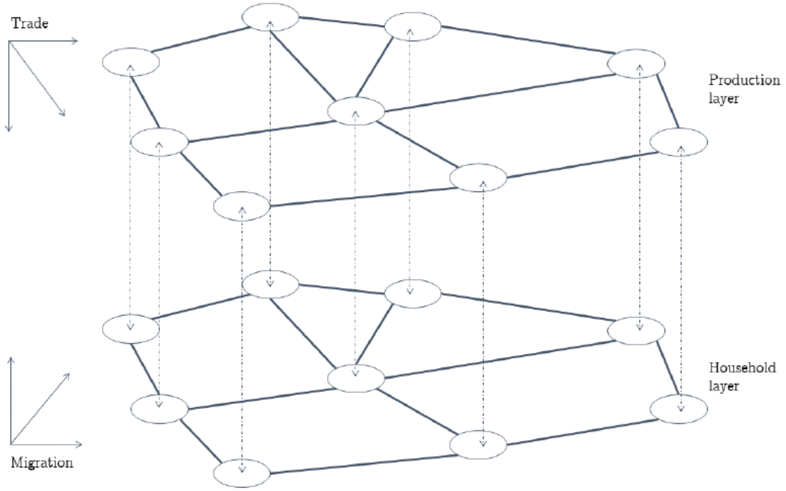
Copulas: joint extreme event modeling



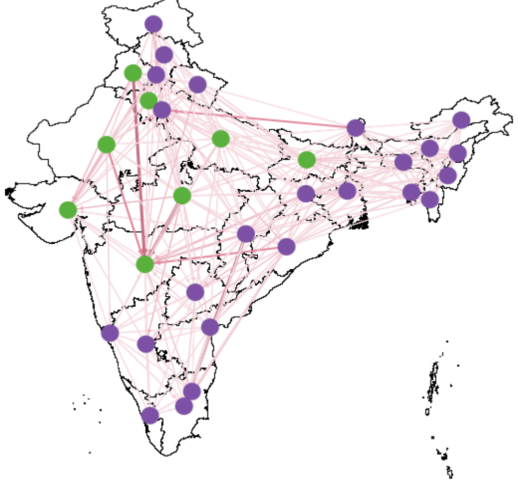


Gaupp et al. (2017) in *Risk Analysis*

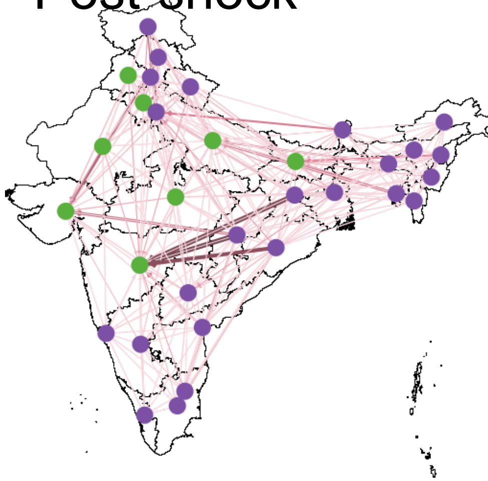
ABMs/networks



Pre-shock

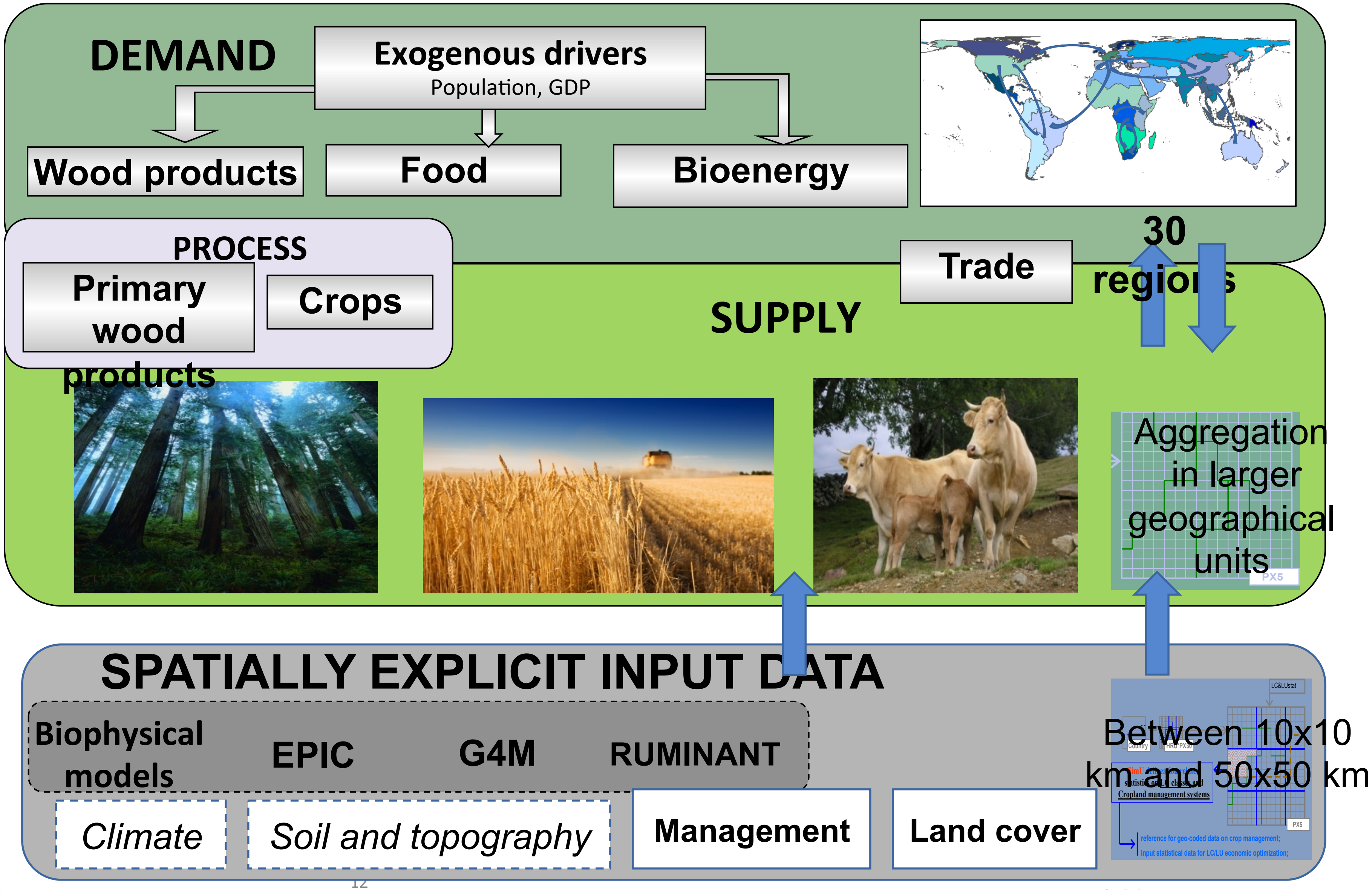


Post-shock

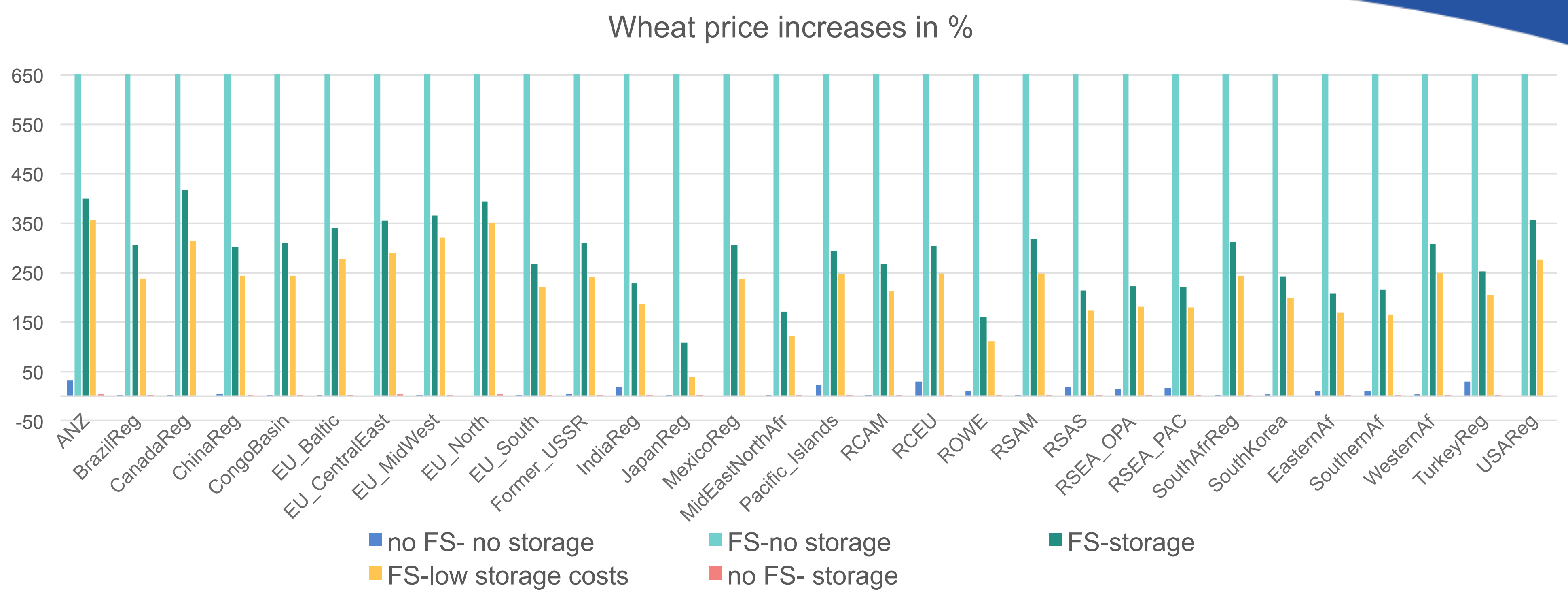


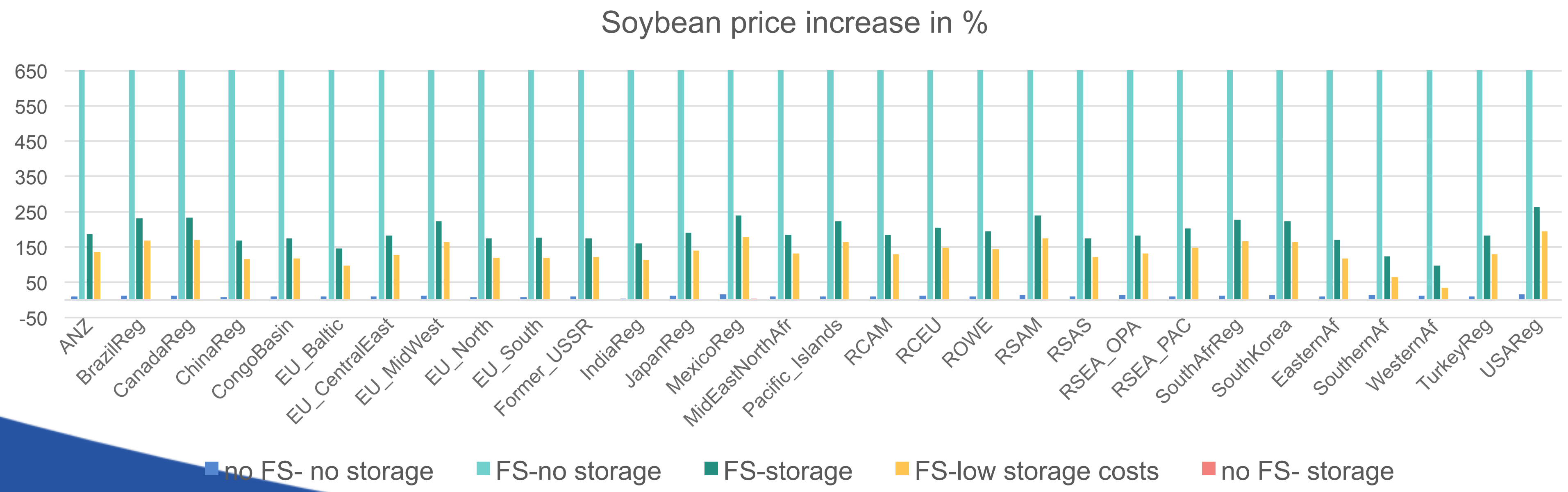
Naqvi et al. (forthcoming) in *OR Spectrum*

IIASA's GLOBIOM model



www.globiom.org



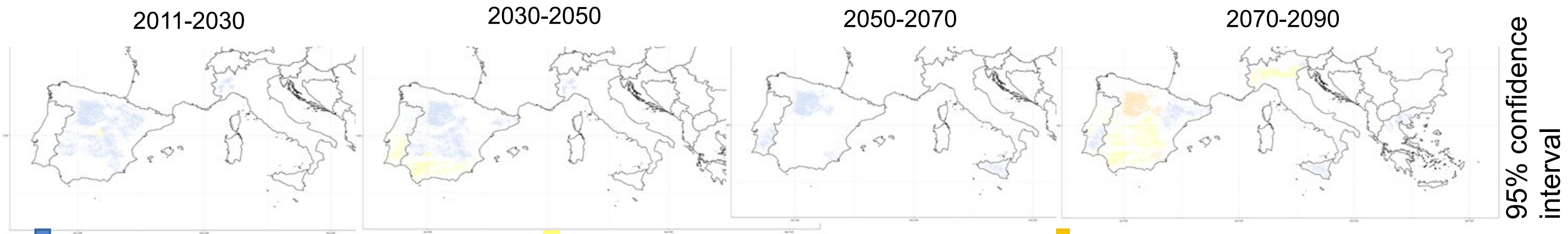


Ermolieva et al.

GLOBIOM-X: Capturing extreme climate events in a partial-equilibrium model

Conventional PE models
(supply = demand at a certain price)
do not capture the short-term production losses and market disturbances because trade and crop-production adjustments occur simultaneously.
Therefore, introduce **a two-step solution framework** in GLOBIOM

Climate models in combination with crop models show **increased magnitude and frequency of climate-related yield shocks**



= return period of 20 years (prob. 0.05) = return period of 10 year (prob. 0.1), = return period of 8 years (prob. 0.12).

Step 1: **Maximize expected revenues** and fix crop-allocation decision

MAX	Producers' expected revenues
UNDER	Constraints
MODEL OUTPUTS	Crop area allocation (Ha)
	Land use change area (Ha)

A yield-shock may take place

Step 2: Solve demand and trade relationships given the known crop allocation and production (losses)

MAX	Producers' profits
	Consumers' utility
UNDER	Constraints
MODEL OUTPUTS	Prices (US$)
	Demand quantities (Tons)
	Production quantities (Tons)
	Trade quantities (Tons)

This allows us to disentangle the effect of the shock to prices spikes, trade, and next-year adjustments…

…In order to analyze the effects on adaptation policies such as trade and stockholding

Boere et al.

Thank you for your attention!

gaupp@iiasa.ac.at

@FranziskaGaupp

soundcloud.com/foodsystemspodcast

Step 2: Fitting a copula and estimate copula parameter

1. Estimate copula parameter

Copula	Relationship with Kendall's τ	Copula
Elliptical copulas (Student t, Normal,..)	$\rho(X,Y) = \sin\left(\frac{\pi}{2}\tau\right)$	*depends on copula*
Frank	$\frac{[D_1(\alpha)-1]}{\alpha} = \frac{1-\tau}{4}$ with $D_1(\alpha) = \frac{1}{\alpha}\int_0^{\alpha}\frac{t}{e^t-1}dt$	$C_\alpha(u,v) = -\frac{1}{\alpha}\ln\left(1+\frac{(e^{-\alpha u}-1)(e^{-\alpha v}-1)}{e^{-\alpha}-1}\right)$
Gumbel	$\hat{\alpha} = \frac{1}{1-\tau}$	$C_\alpha(u,v) = \exp\left\{-\left[(-\ln u)^\alpha + (-\ln v)^\alpha\right]^{1/\alpha}\right\}$

Key concept. If we feed the arbitrary variable X through its own cdf, we obtain a very special transformed random variable, which is called the grade of X

$$U \equiv F_X(X). \tag{3}$$

The distribution of the grade is uniform on the unit interval regardless of the original distribution f_X

$$U \sim \mathrm{U}_{[0,1]}, \tag{4}$$

The simple proof of this result proceeds as follows

$$\begin{aligned} F_U(u) &\equiv \mathbb{P}\{U \leq u\} = \mathbb{P}\{F_X(X) \leq u\} \\ &= \mathbb{P}\left\{X \leq F_X^{-1}(u)\right\} = F_X\left(F_X^{-1}(u)\right) = u. \end{aligned} \tag{5}$$

Therefore $F_U(u) = u$, which is the cdf of a uniform distribution.

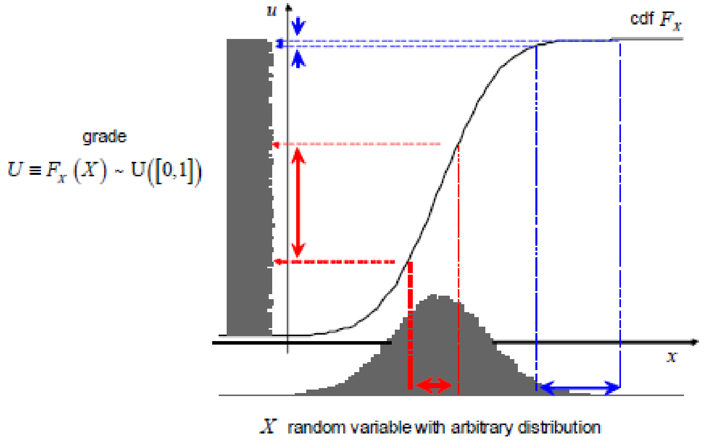


Figure 1: The cdf maps an arbitrary random variable into a uniform variable

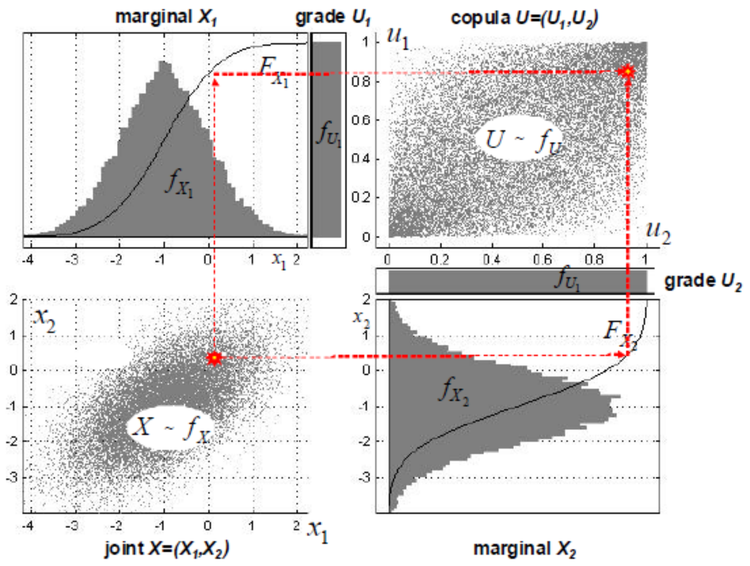
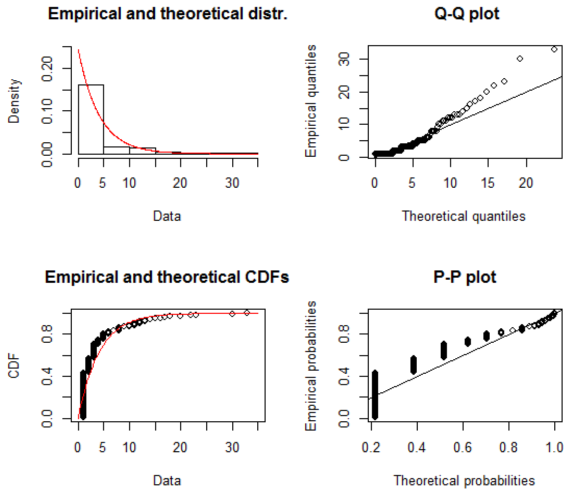
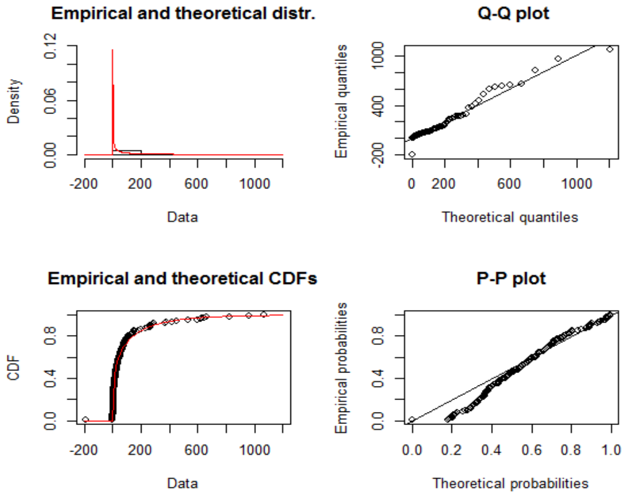


Figure 2: Copulas are non-linear standardizations of multivariate distributions

Example: Drought modeling with copulas (2)



Observed drought duration data fitted to an exponential distribution.



Observed drought severity fitted to a gamma distribution.

$\longrightarrow \quad \hat{\tau} = 0.699$

For Clayton copulas:

$$\tau = \frac{\theta}{(\theta+2)}$$

-> $\hat{\theta} = 4.645$

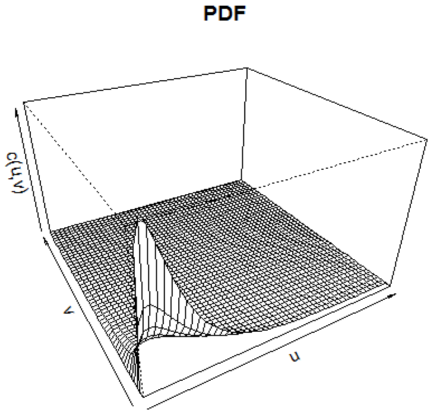


Fig 22: Popular copula families