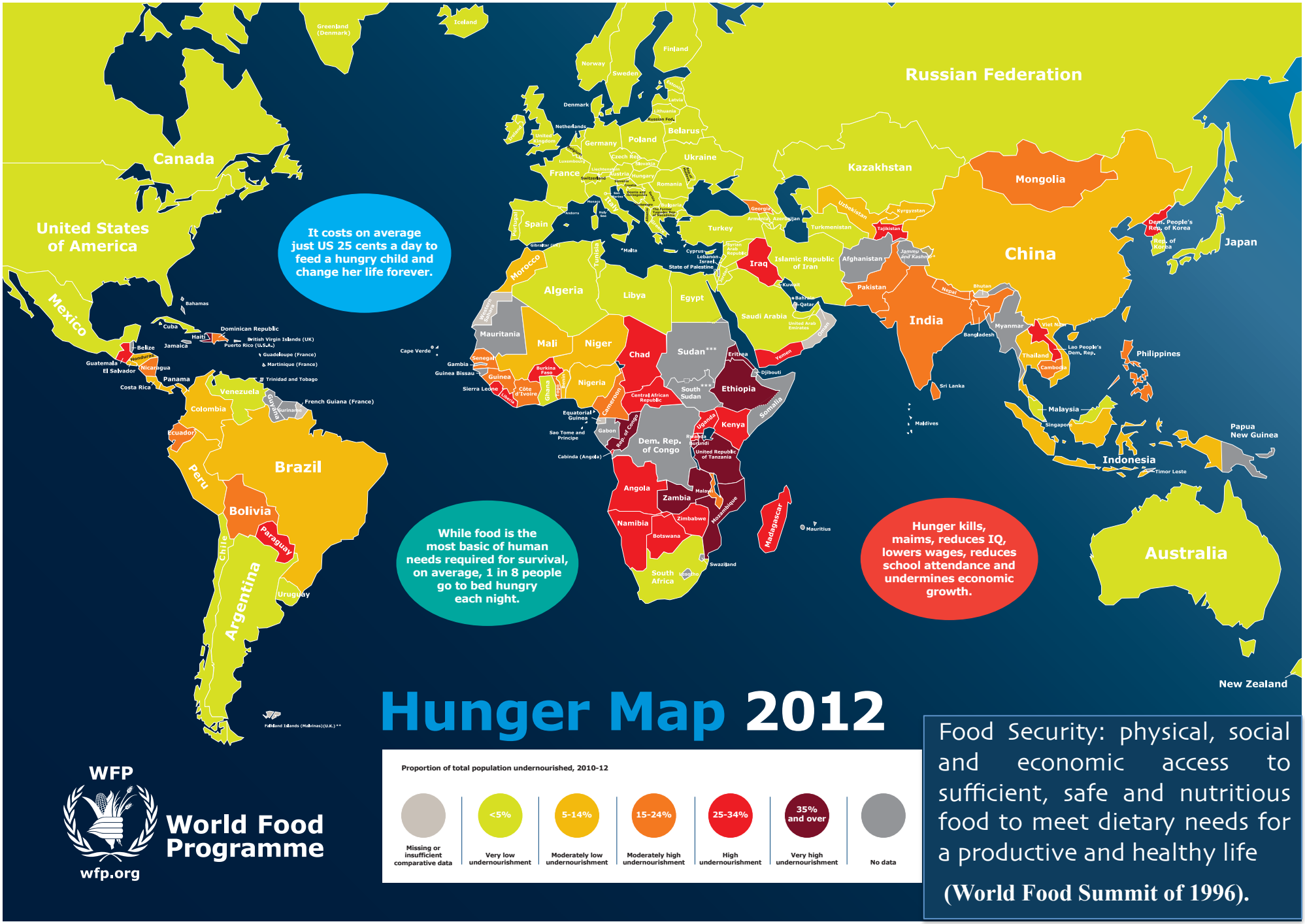
Water-controlled wealth of nations:

Using Water Footprints to Estimate Nations Carrying Capacities and Demographic Sustainability

PNAS, Vol. 110 no. 11 4230-4233 (2013)

Samir Suweis, Andrea Rinaldo,

Amos Maritan and Paolo D'Odorico



Hunger Map 2012

WFP
World Food Programme
wfp.org

Food Security: physical, social and economic access to sufficient, safe and nutritious food to meet dietary needs for a productive and healthy life

(World Food Summit of 1996).

The Water footprints or Virtual Water concept

"Over the coming decades, feeding a growing global population and ensuring food and nutrition security for all will depend on increasing food production. This, in turn, means ensuring the sustainable use of our most critical finite source - water"

Ban Ki-moon, World Water Day, 15 march 2012

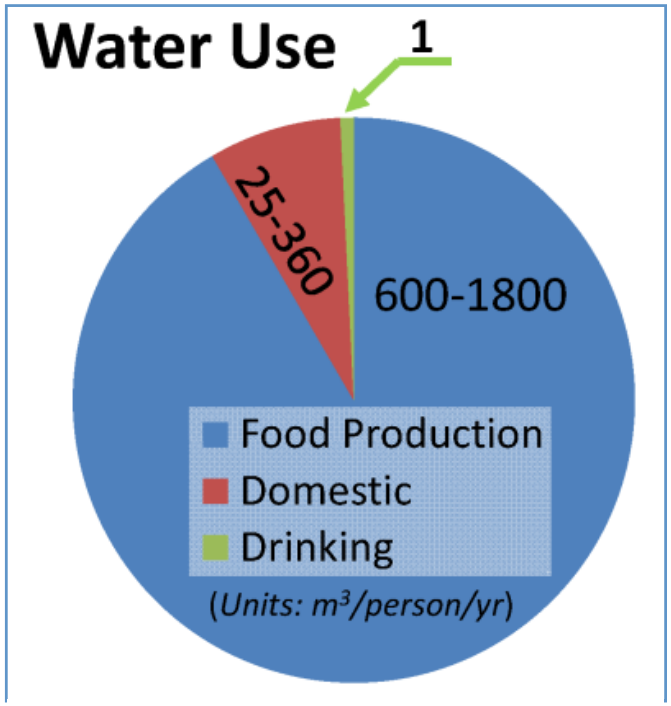
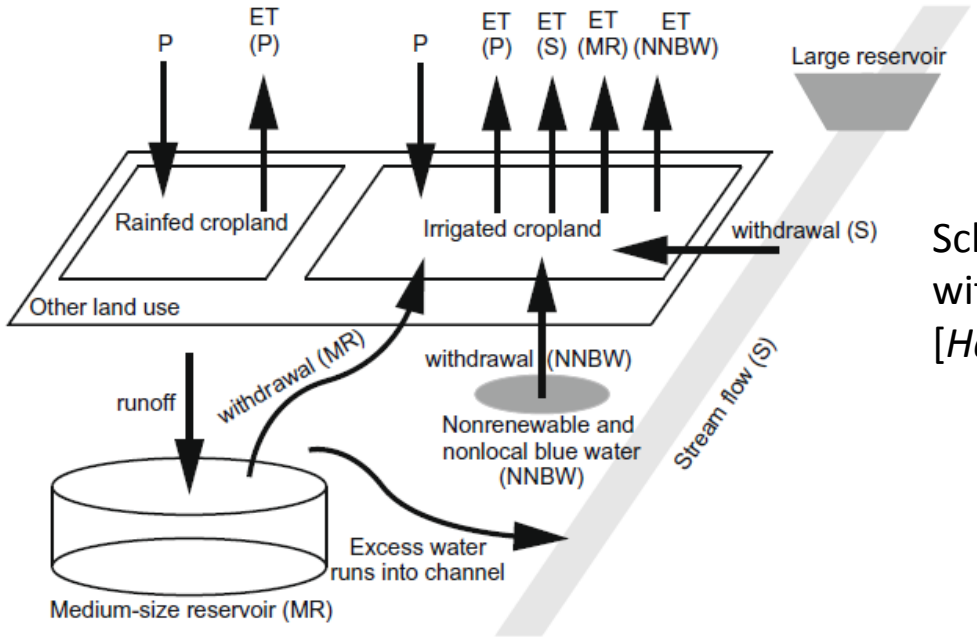


Figure . *Annual water use per capita (data from Falkenmark et al., 2004).*

The Local Carrying Capacities of Nations

- WF determined using bottom-up hydrological modeling at 5 by 5 arc spatial resolution.
- Average values are calculated over 10 years periods.
- Calibration: AQUASTAT and UN statistical division database (FAO, 2010b, UNSD, 2010°).

$$K_{loc} = \frac{WF_{crop} + WF_{grazing} + WF_{livestock}}{W_c}$$

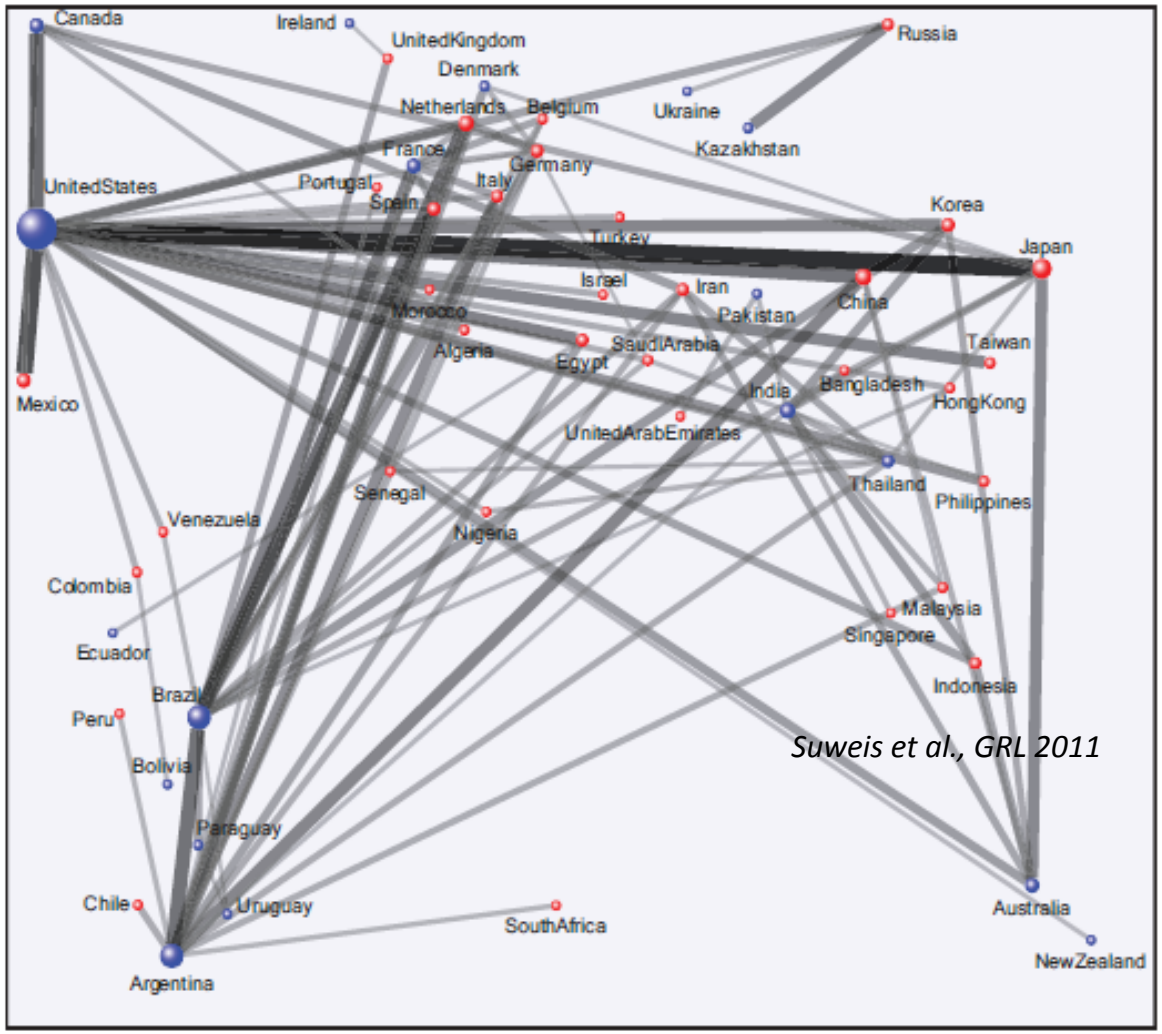


MekonnenMM, Hoekstra AY (2011)

Schematic diagram of water withdrawals in the H08 model [*Hanasaki et al.,* 2008]

The Virtual Carrying Capacities of Nations

$$K_V^i = K_{loc}^i + \frac{VW_I(i) - VW_E(i)}{W_c^i}$$



TFM =trade food matrix

TFM_y (i,j) = volume of commodity y traded from *i* and nation *j*.

$$a_{ij}^y = \Theta[\mathrm{TFM}_y(i,j)]$$

$$w_{ij}^y = \mathrm{TFM}_y(i,j) \cdot \mathrm{VW}_y(i)$$

$$\mathrm{VW}_E(i) = \sum_y \sum_{j=1}^{N} w_{ij}^y$$

Water Wealth of Nations

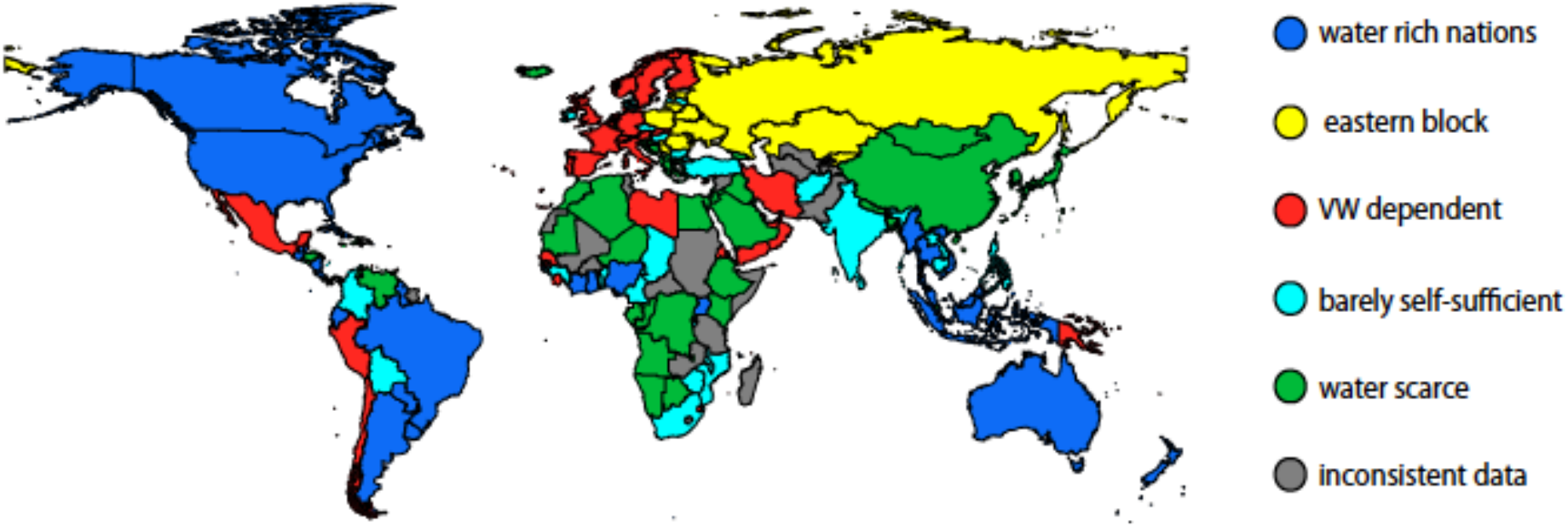
$$\frac{dx_i}{dt} = \alpha_i x_i \left(1 - \frac{x_i}{K_i}\right)$$

Countries Demographic Dynamics

$$K \rightarrow K_{loc} \; or \; K_V$$

$$\gamma_i = \frac{1}{x_i(t)} \frac{[x_i(t+\Delta t) - x_i(t)]}{\Delta t} \rightarrow \alpha_i$$

$$x_i(t) = \frac{K_i x_{0,i} e^{\alpha_i t}}{K_i + x_{0,i} e^{\alpha_i t} - x_{0,i}}$$



$$\langle x \rangle << K_{loc}; \quad K_{loc} > \langle x \rangle > K_V; \quad \langle x \rangle \approx K_{loc}; \quad \langle x \rangle > K_V$$

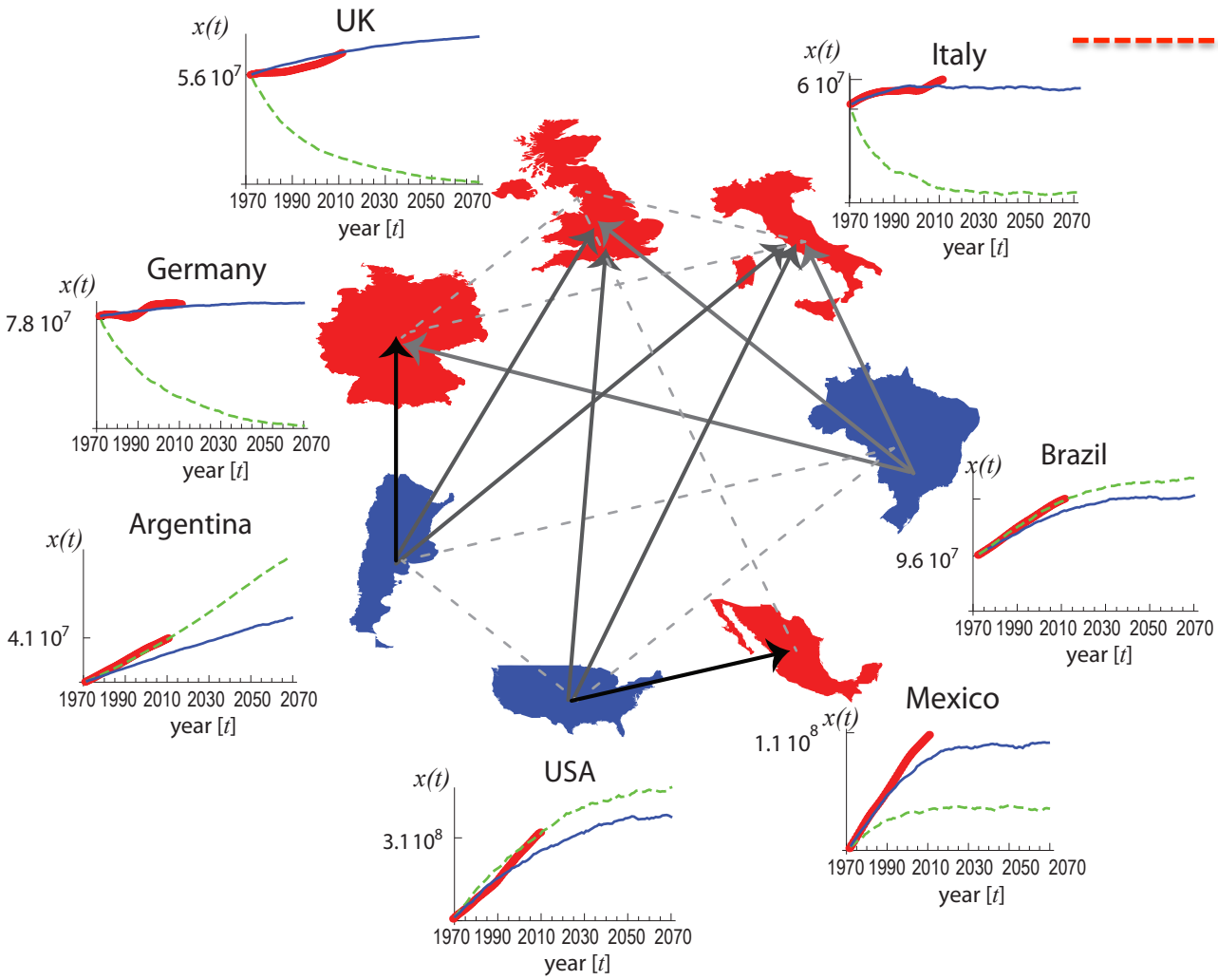
Water Global Unbalance

- Virtual Water Dependent
- Water Rich

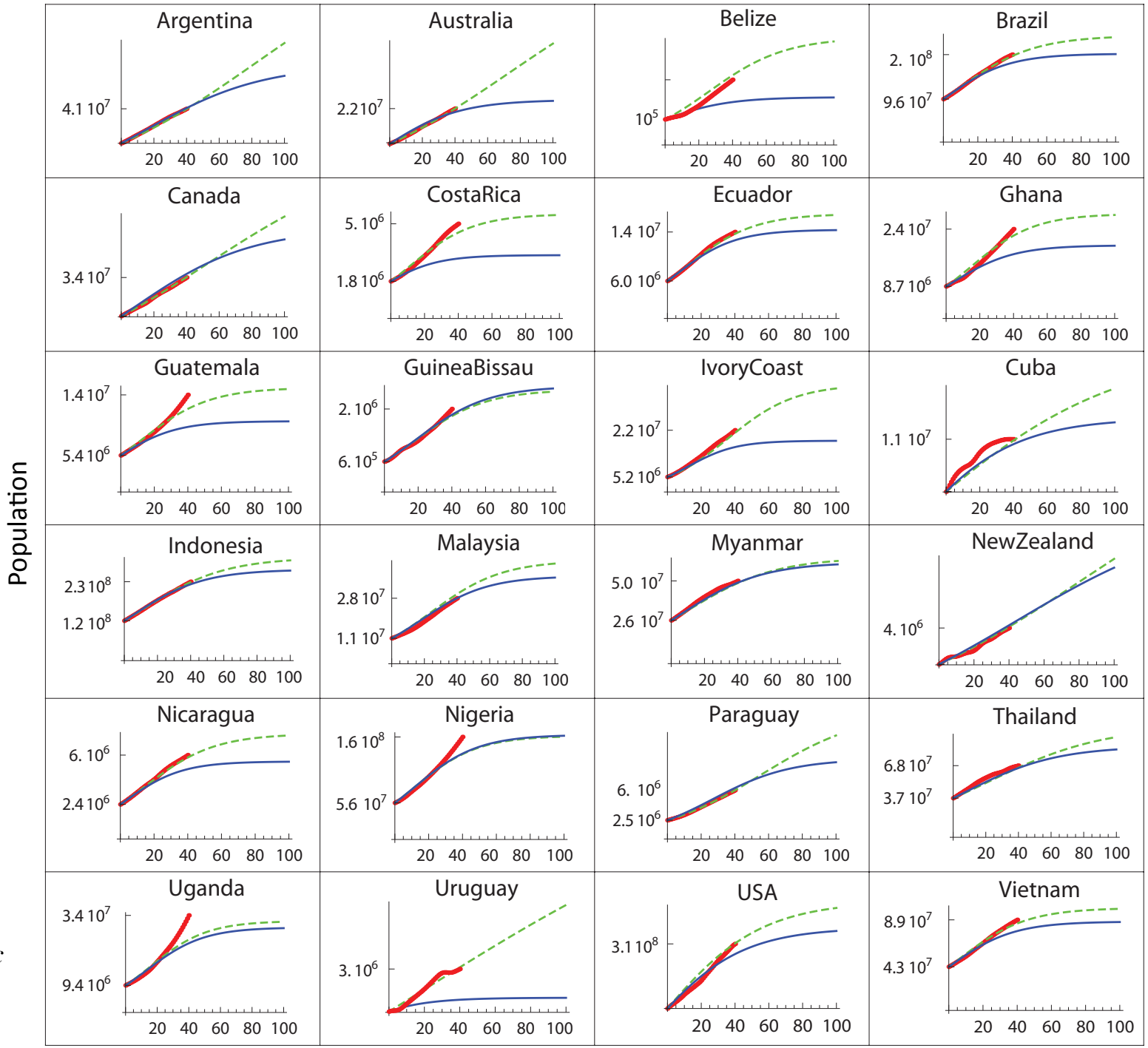
$K = K_V$

$K = K_{loc}$

Data



Water Rich Countries

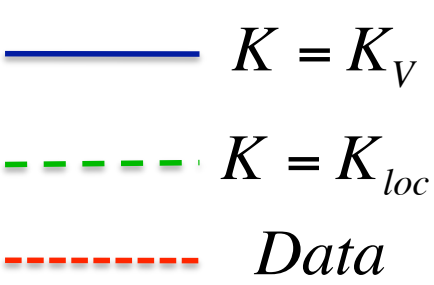


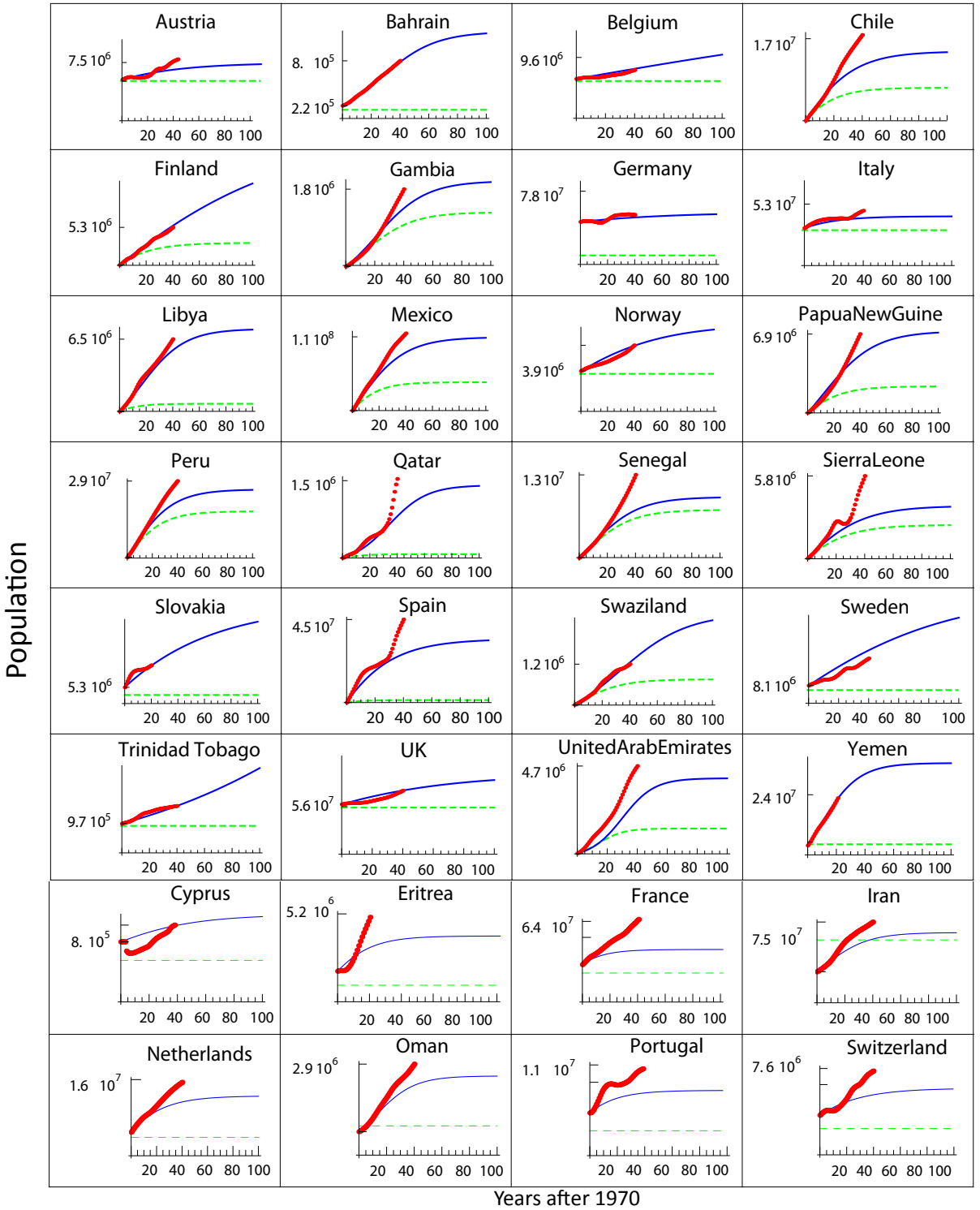
$K = K_V$

$K = K_{loc}$

Data

Virtual Water Dependent Countries



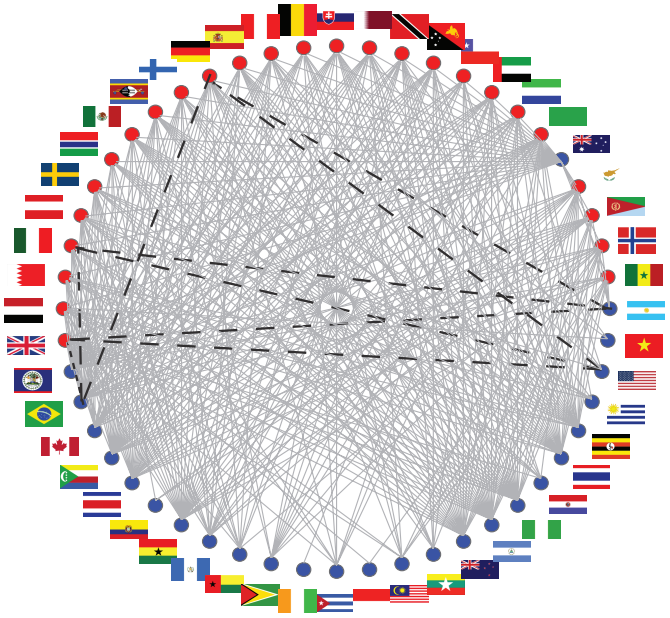


Modelling Sustenability of VW Dependent Countries Population

System of coupled differential equations

$$\begin{cases} \dfrac{dx_i}{\mathrm{dt}} = \alpha_i x_i \left(1 - \dfrac{x_i}{K^i{}_{loc}}\right) & \text{for i=Rich Water} \\ \dfrac{dx_j}{\mathrm{dt}} = \alpha_j x_j \left(1 - \dfrac{x_i}{K^j{}_{loc} + \sum_i^{\mathrm{Rich}} \frac{a_{ji}}{d_i}(K^i{}_{loc} - x_i)\frac{VW_i}{VW_j}}\right) & \text{for j=VW dependent} \end{cases}$$

Diets!

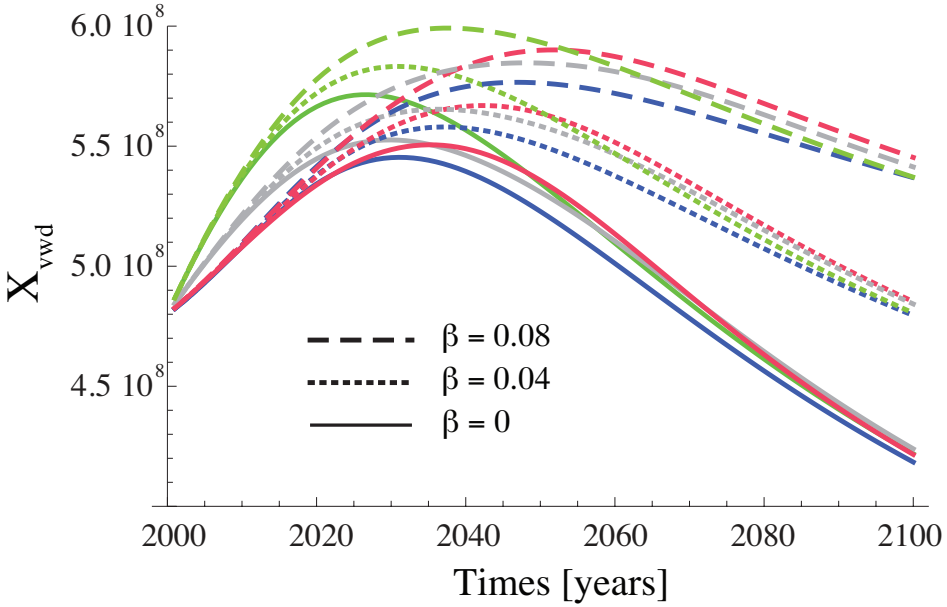


Virtual Water Dependent

Water Rich

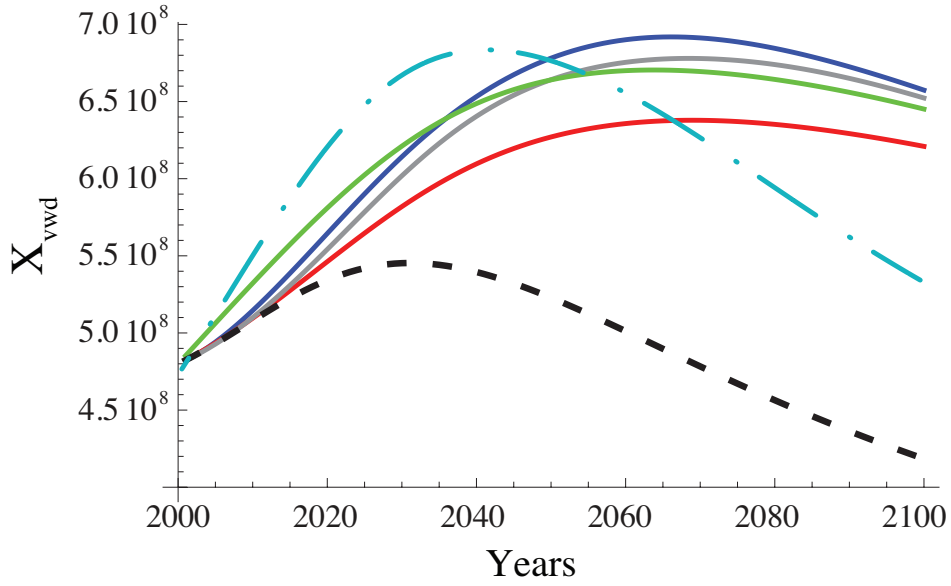
Graph Topology a_{ij}

Results & Effect of Network Topology



β= cooperative strength

- Random graph
- Scale-free network
- Small world network
- Topological properties similar to those observed in the real global VW trade network

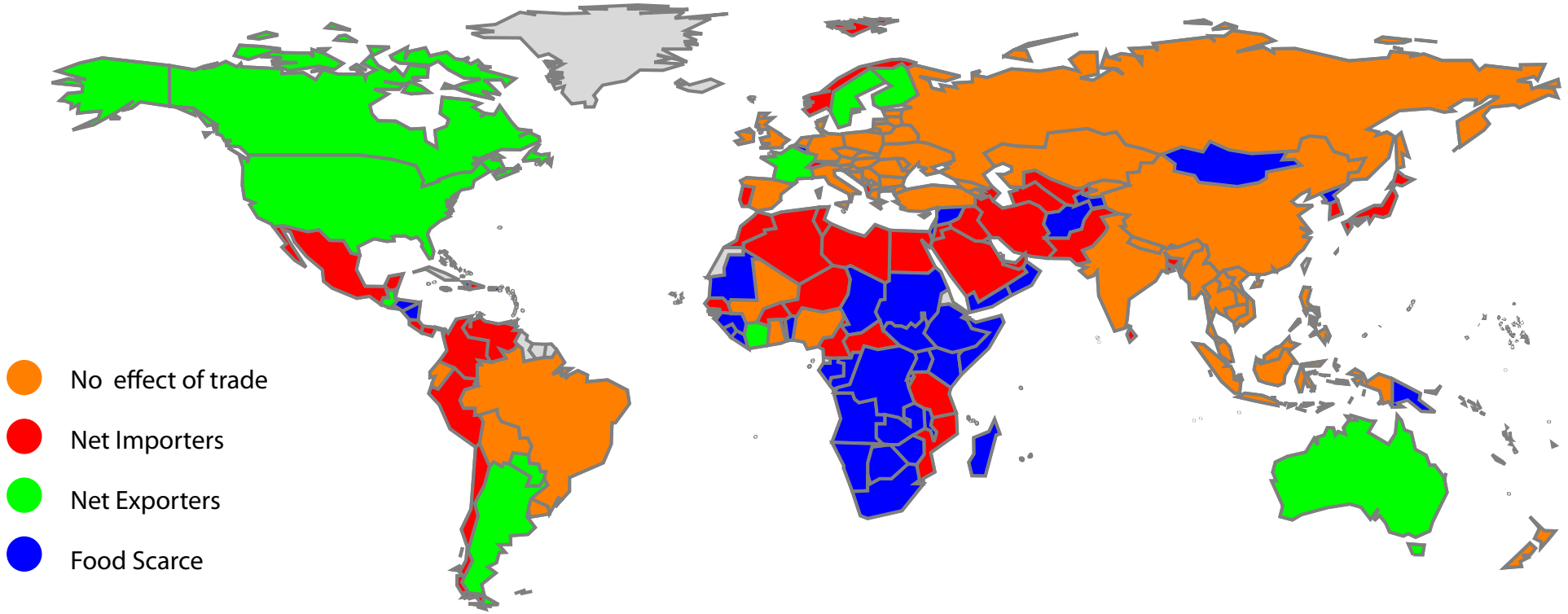


$K_{loc}(t)=K_{loc}(1+\varepsilon(t))$ and decreasing $W_c(t)$

Rockström, J., et al. GRL 39.15 (2012).

- Positive feedback between demographic growth and technological innovations
- Static

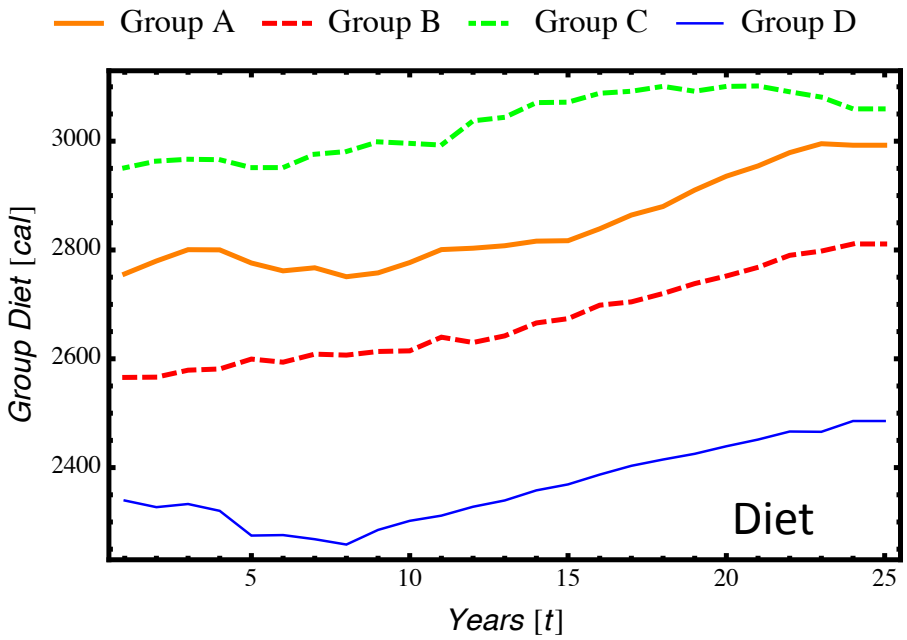
Using Food Trade Data - Temporal Networks

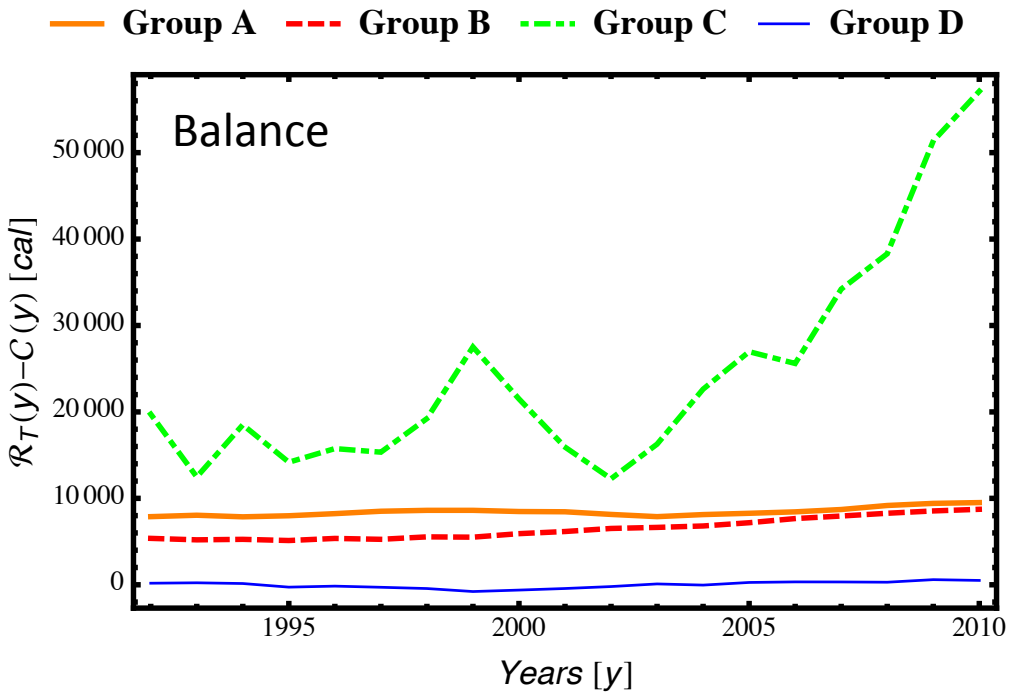


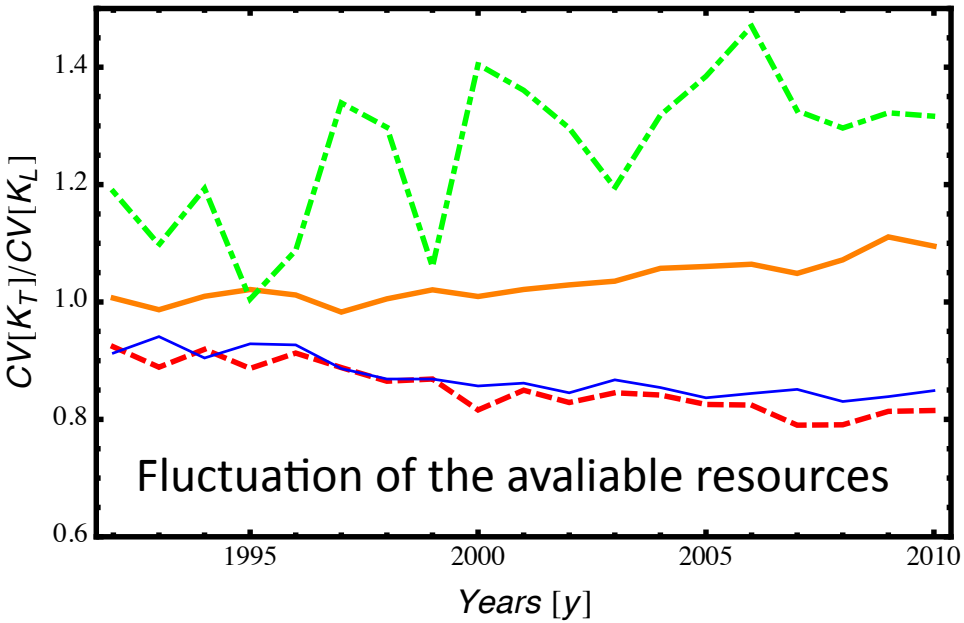
$$x(t+\Delta t) = \frac{K(t)\mathrm{x}(\mathrm{t})e^{\alpha(t)\Delta t}}{x(t)sgn(\alpha(t)) + K(t) + x(t)e^{\alpha\Delta t}sgn(\alpha(t))}.$$

Temporal Food Trade Patterns and Stability, in preparation

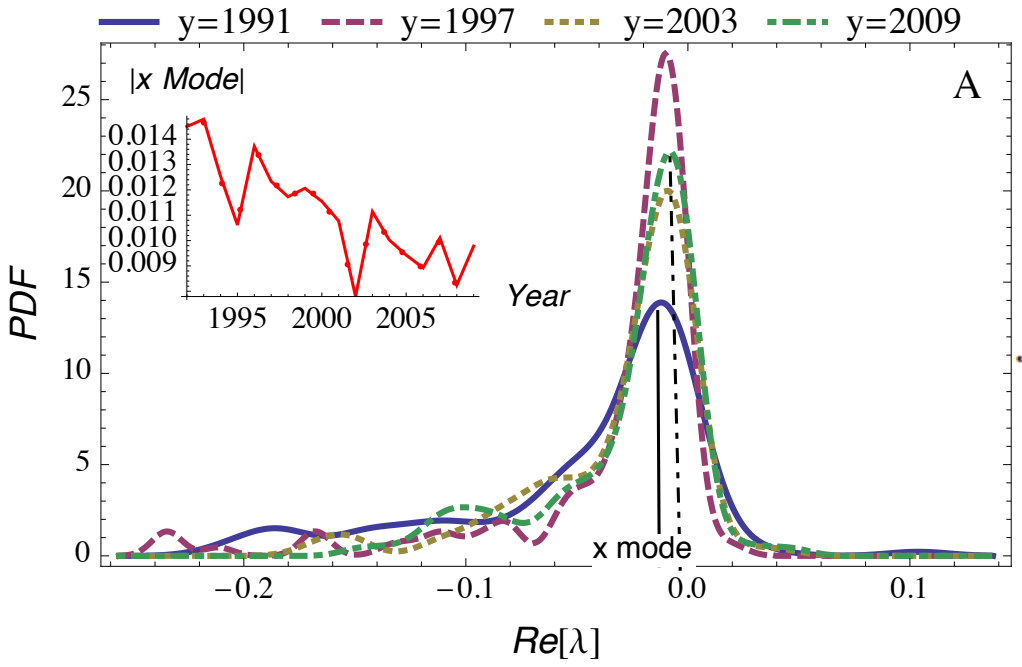
Does globalization Increases stability?







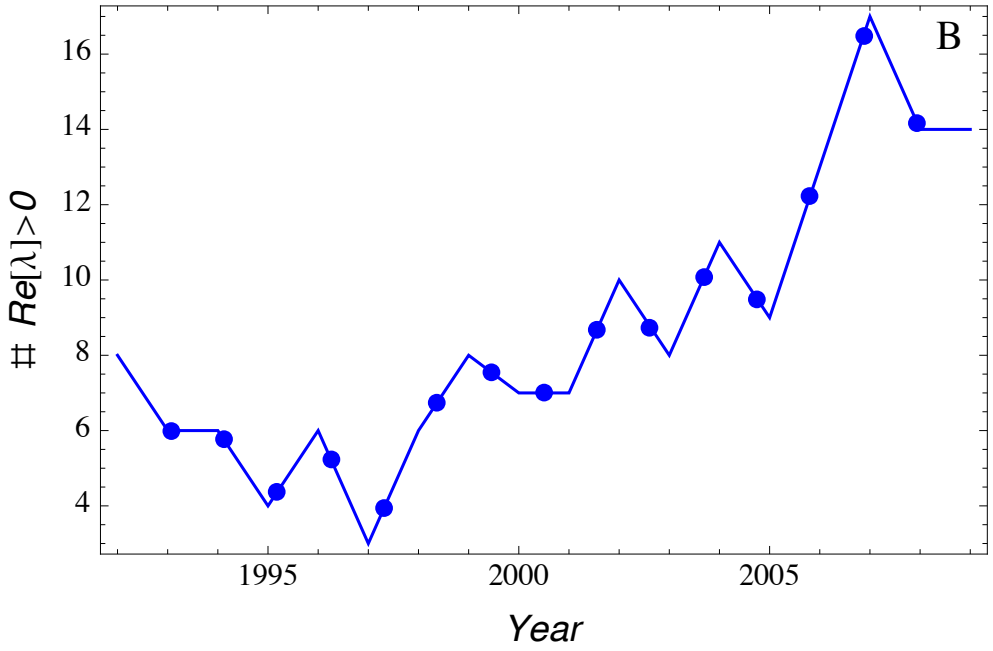
Stability of the Food trade Network



$$J_{ij}(t) \equiv \frac{\partial f_i(\mathbf{x},t)}{\partial x_j}\Big|_{\mathbf{x}(t)} = \delta_{ij}\alpha_i(t)\left(1 - 2\frac{sgn(\alpha_i(t))x_i(t)}{K_{T,i}(t)}\right)$$

Effect of the network

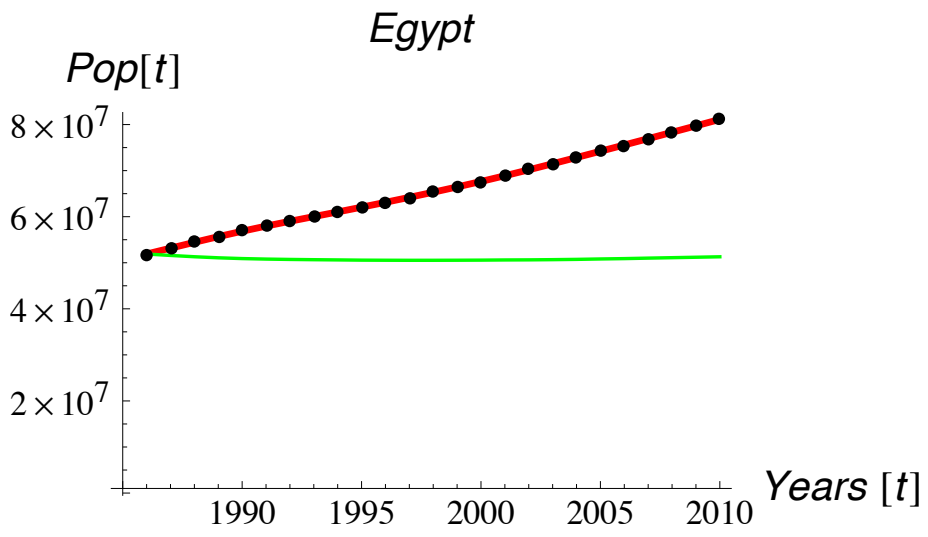
If $\mathrm{Re}(\lambda_i > 0)$ → $x_i(t)$ is very sensitive to external perturbations

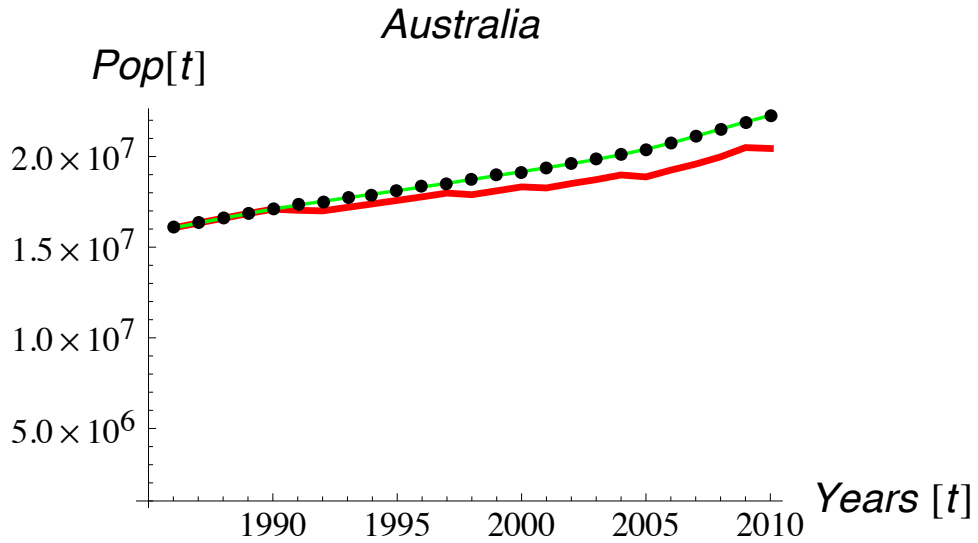


Country
Netherlands
Malaysia
United Arab Emirates
Myanmar
Singapore

Conclusions & Perspectives

- Side-effects of the globalization of resources
- Unbalance between the rate of growth in water rich countries and the water resources exported to virtual water dependent countries
- Decreasing stability in time of the food-demographic coupled system





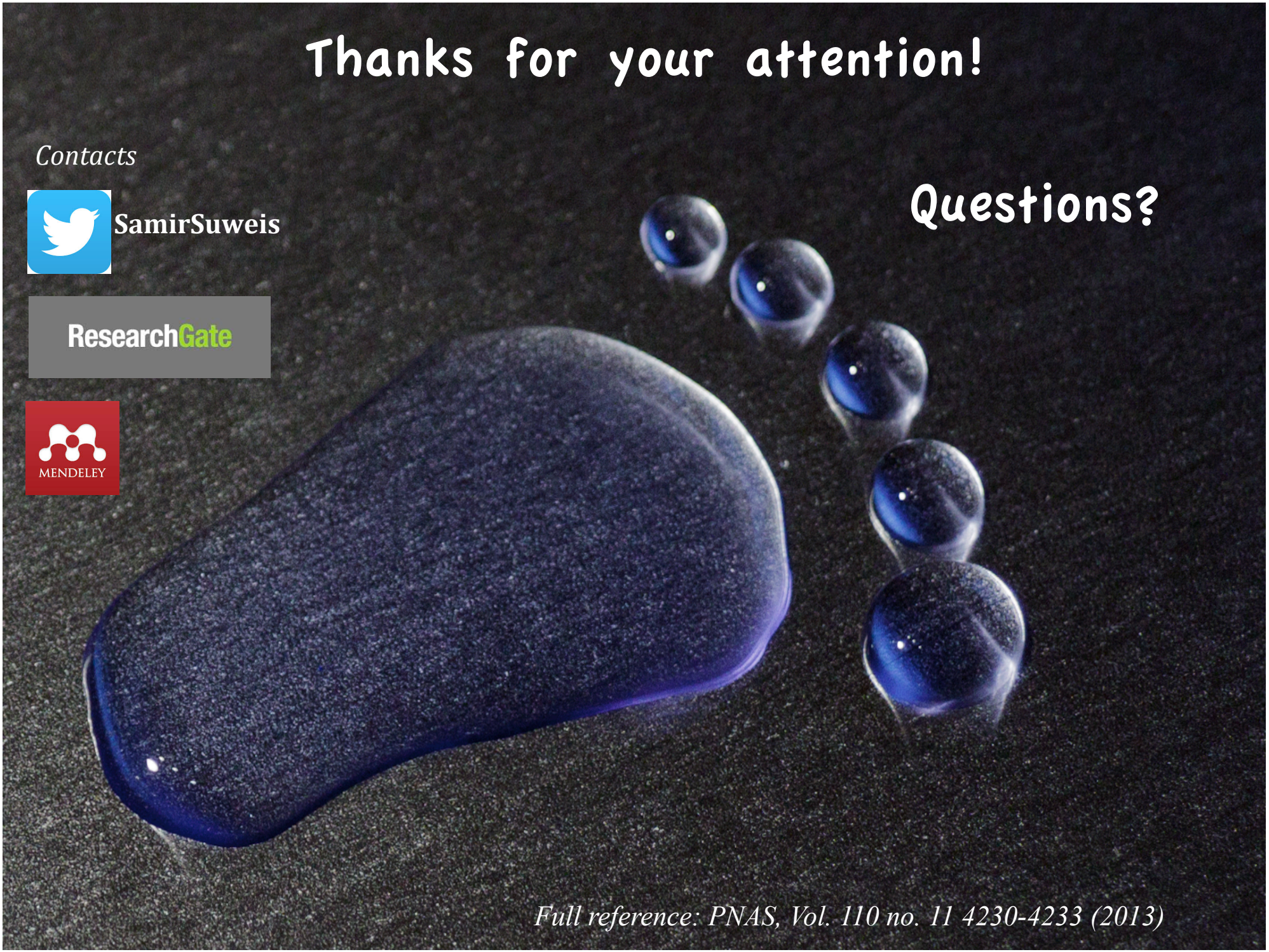
Conclusions & Perspectives

DATA ANALYSIS

- Estimate the uncertainity of VW footprint calculations
- Create public and shared databases so to work with the same data
- Data on Food Stock, Food Waste,…

MODELLING

- Is there any optimal network topology in terms of water saving?
- How to quantify waste or detrimental links in the virtual water trade networks?
- Robustness to perturbations and fragility of the network


Thanks for your attention!
Contacts
SamirSuweis
ResearchGate
MENDELEY
Questions?
Full reference: PNAS, Vol. 110 no. 11 4230-4233 (2013)