Structure and resilience of global food trade networks

JC De Gourcuff, P. Ciais, D. Makowsky, &
Marc Barthelemy

CEA, Institut de Physique Théorique, Saclay, France
EHESS, Centre d' Analyse et de Mathématiques sociales, Paris, France

marc.barthelemy@ipht.fr
www.quanturb.com

The global wheat trade network

- In 2019, wheat and wheat products accounted for at least one-tenth of the food basket of about 5.9 billion people in some 120 countries
- More than half of the world's production (wheat and wheat products) is provided by just 5 countries.
- There are shocks (abrupt partial or complete reduction of exports) in this system: Extreme weather conditions and wars
- These shocks can potentially affect a very large number of individuals: modeling the propagation of shocks is crucial for food security
- A difficulty: Many constituents interact over various time and spatial scales (countries, companies, institutions, etc).

The global wheat trade network: Russia and Ukraine

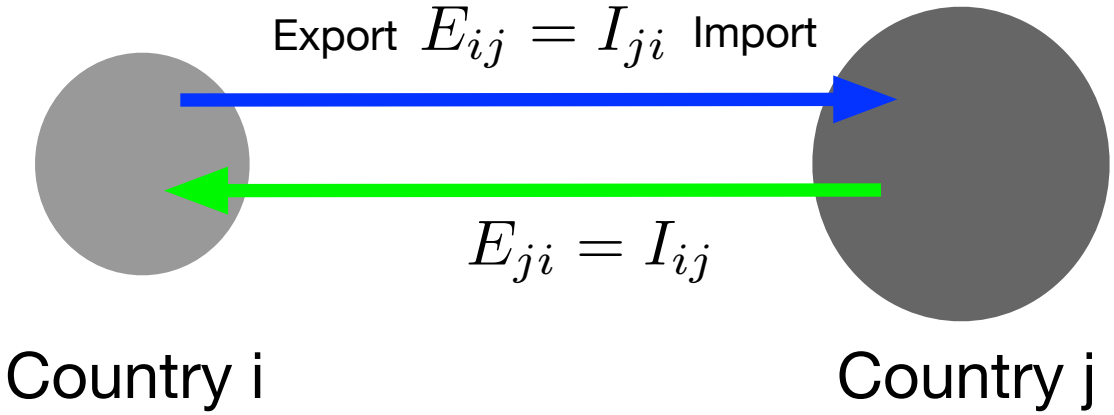
- Russia and Ukraine together represent the world largest wheat export capacity
  - Russia: 10.3% (20%) of the world wheat production (trade)
  - Ukraine: 3.4% (10%)

- Disruptions of their export flows might have major humanitarian consequences

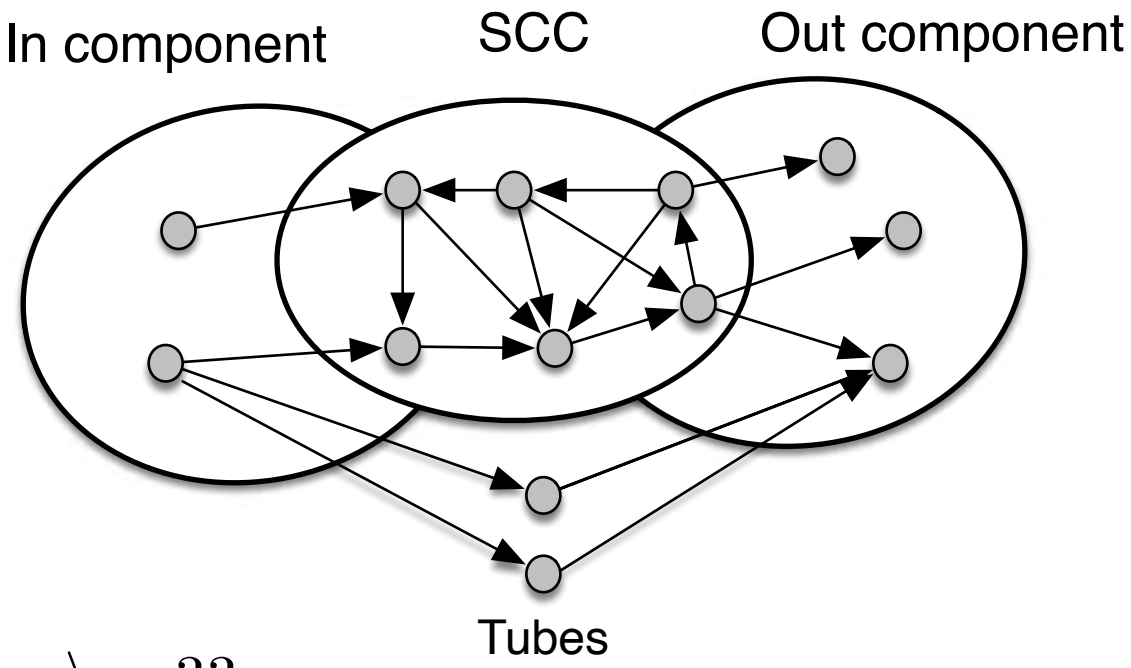
Can we model the shock propagation and its impact ?
Parsimonious and robust model ?

The global food trade network: a complex system

- Data: FAO database (2022)
- 170 countries, ~6000 edges, ~7.6 billion individuals
- Nodes: countries, directed, weighted edges



The global wheat trade network



$\langle k_{in} \rangle = \langle k_{out} \rangle \approx 33$

Components stable over time (2010-2019)

- Strongly connected component: ~130 countries, diameter=5, average distance=1.95
- Out-component (pure importers) ~40 countries

From wheat data to the prevalence of undernourishment

- Percentage p of the population that falls under the minimum dietary energy requirement M (daily caloric intake to stay healthy – country dependent)

- The FAO assumes that the food supply available per inhabitant and per year is distributed according to a lognormal of average C^{tot}(kcal/cap/year) and variance σ^2

$$p = \Phi\left(\frac{\ln(M) - \ln(C^{tot})}{\sigma^2}\right)$$

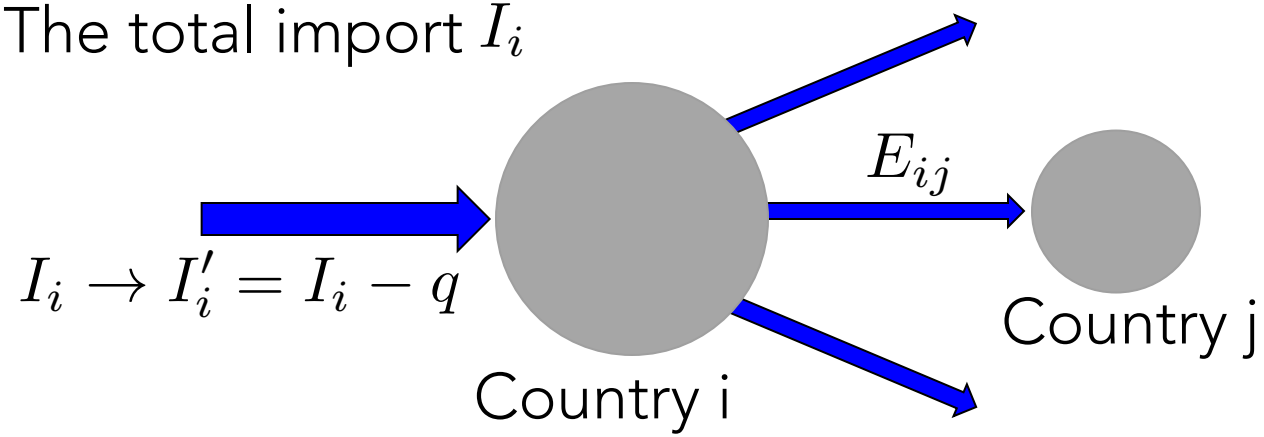
where Φ is the cumulative for the standard lognormal

- Knowing the supply C^{tot} , we can then compute the prevalence of undernourishment p

Shock propagation mechanism

Proportional strategy (Tamea et al, 2016)

Decrease of q of
The total import I_i



$$E_{ij} \rightarrow E'_{ij} = E_{ij} - q\frac{E_{ij}}{\sum_j E_{ij}}$$

Available
wheat supply

$$S_i \rightarrow S'_i = I'_i - E'_i + P_i$$

Shock propagation mechanism

Proportional strategy

- Before and after the shock

$$I_i \rightarrow I_i' = I_i - q$$

$$E_{ij} \rightarrow E_{ij}' = E_{ij} - q\frac{E_{ij}}{\sum_j E_{ij}}$$

Available wheat supply

$$S_i \rightarrow S_i' = I_i' - E_i' + P_i$$

- Worst case scenario for the demand D_i

$$D_i' = \begin{cases} D_i \text{ if } S_i' > D_i \\ S_i' \text{ otherwise} \end{cases}$$

New food supply (f_w share of wheat in the food basket) $x_w = \frac{S_i'}{D_i}$

$$C_{tot}' = C_{tot}[1 + f_w(x_w - 1)] \text{ for } x_w < 1$$

$$C_{tot}' = C_{tot} \text{ otherwise}$$

Model: recap

Proportional strategy

- Shock (reduction of export for a country)
- Propagate the shock (proportional strategy)
- For each country compute the amount of food available after the shock C'_{tot}
- From C'_{tot} compute the prevalence of undernourishment p

Illustration:
The Ukraine crisis

The global wheat trade network: Russia and Ukraine

- Russia and Ukraine together represent the world largest wheat export capacity
  - Russia: 10.3% (20%) of the world wheat production (trade)
  - Ukraine: 3.4% (10%)

- Impact of disruptions of their export flows ? We will focus on a decrease of 50% of Ukrainian exports

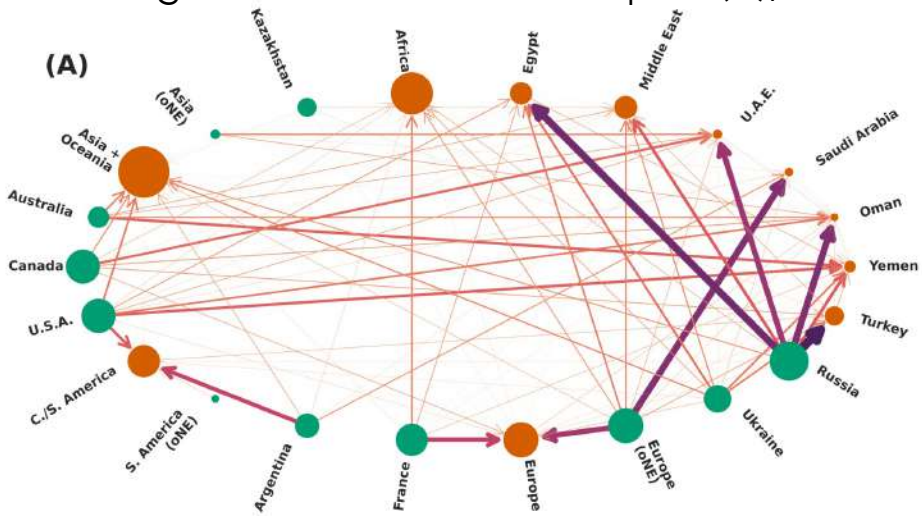
- This export drop represents
  - 3.8% of the total amount of wheat and wheat products that reach the global market.
  - The impact of the shock cascade on the GWTN structure is substantial: the number of strictly importing countries goes from 39 to 100, the number of edges is roughly divided by 1.7 and the average quantity exported through a single trade relationship has be multiplied by 1.6

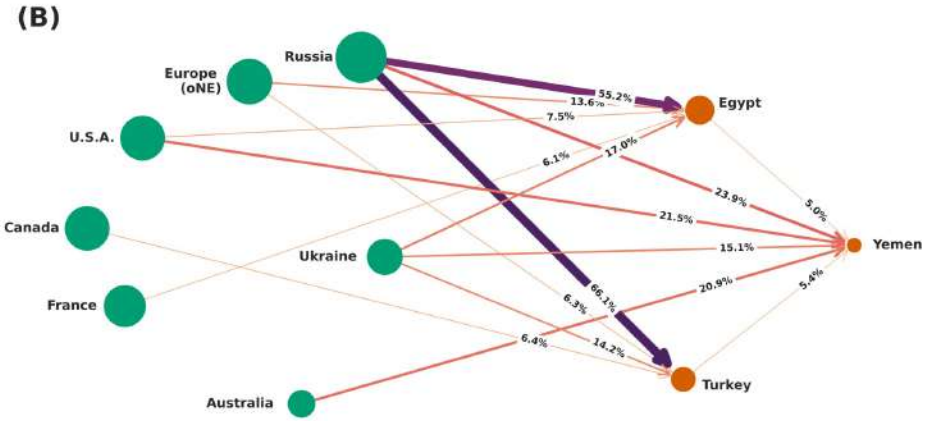
Different paths

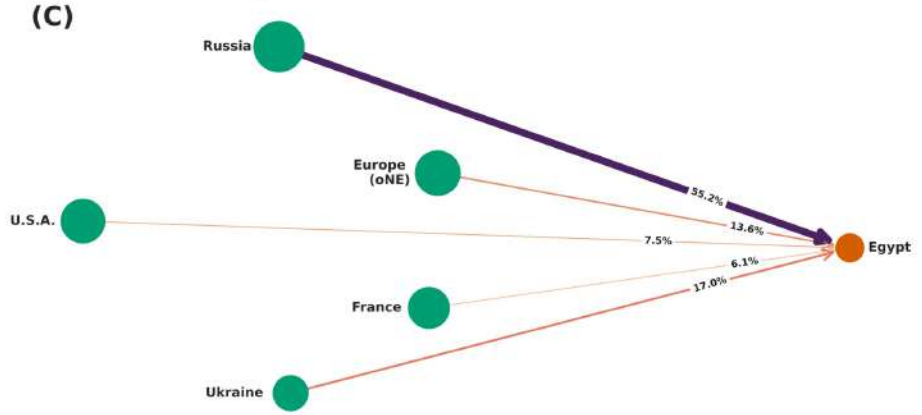
$E_i > I_i$

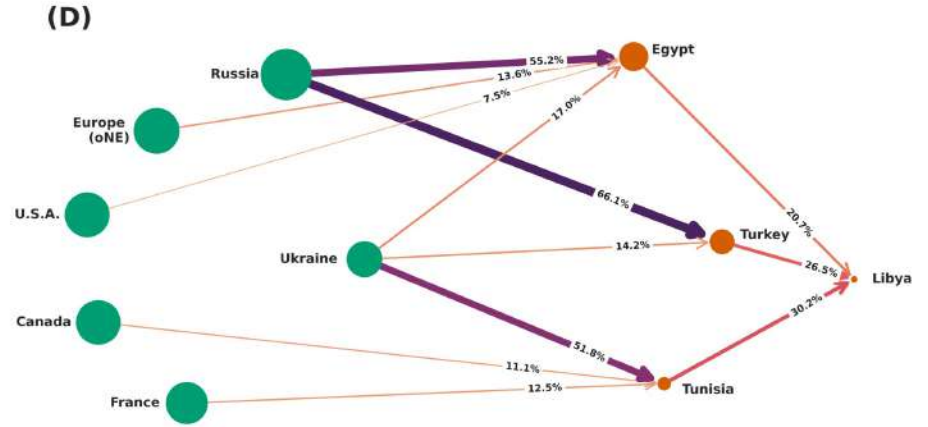
$E_i < I_i$

Wheat supply-chains of Yemen (A and B), Egypt (C) and Libya (D) for the 2019 GWTN.
Pruning: Yemen 100% wheat import (A), 91.95% (B). Egypt 99.44% (C), Libya 77.37% (D).





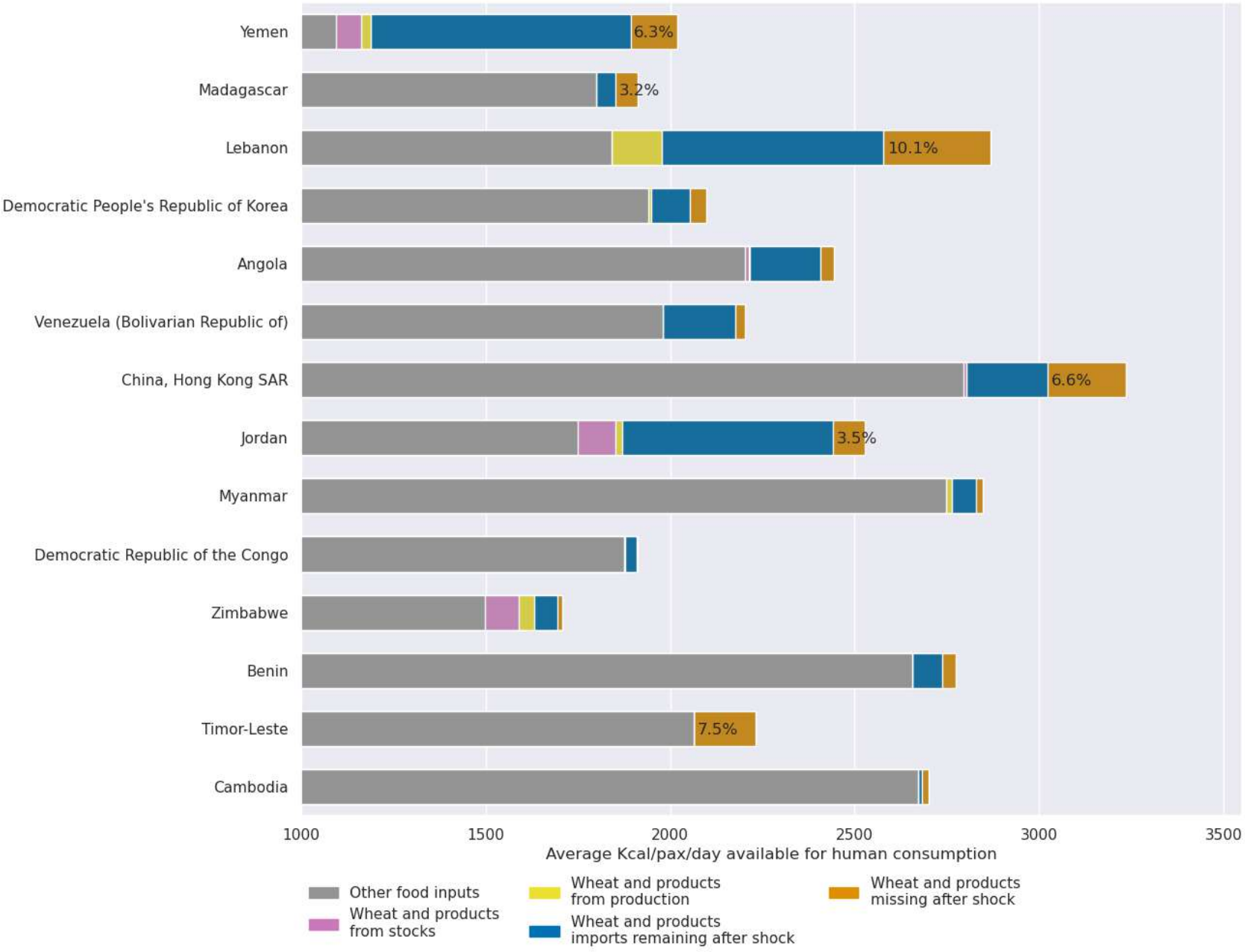




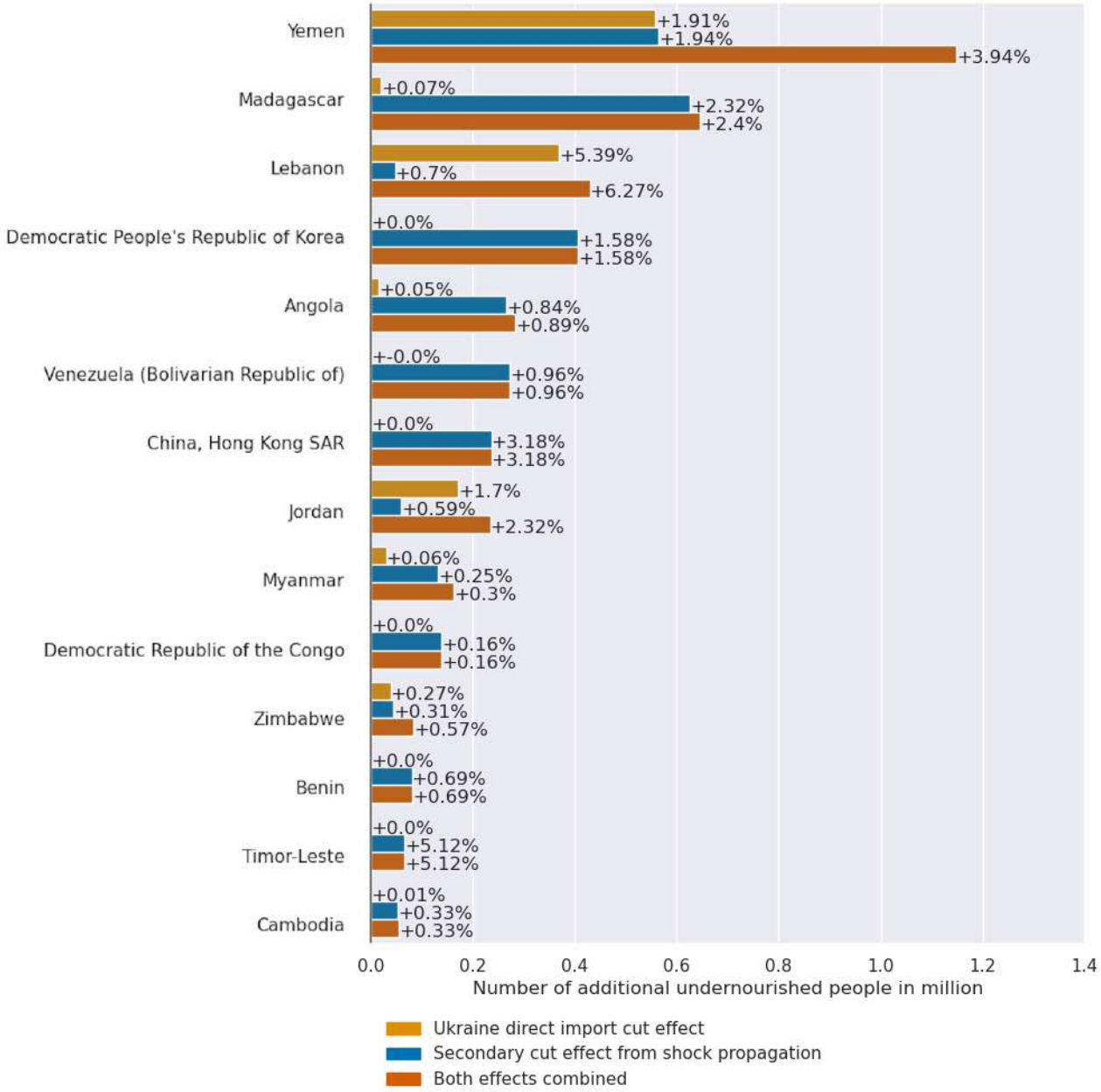
We distinguish 3 categories of countries:

- exclusively directly from net positive exporters (Egypt, (C))
- import exclusively from intermediaries (Lybia, (D))
- import from both net positive and intermediaries such as Yemen (B).

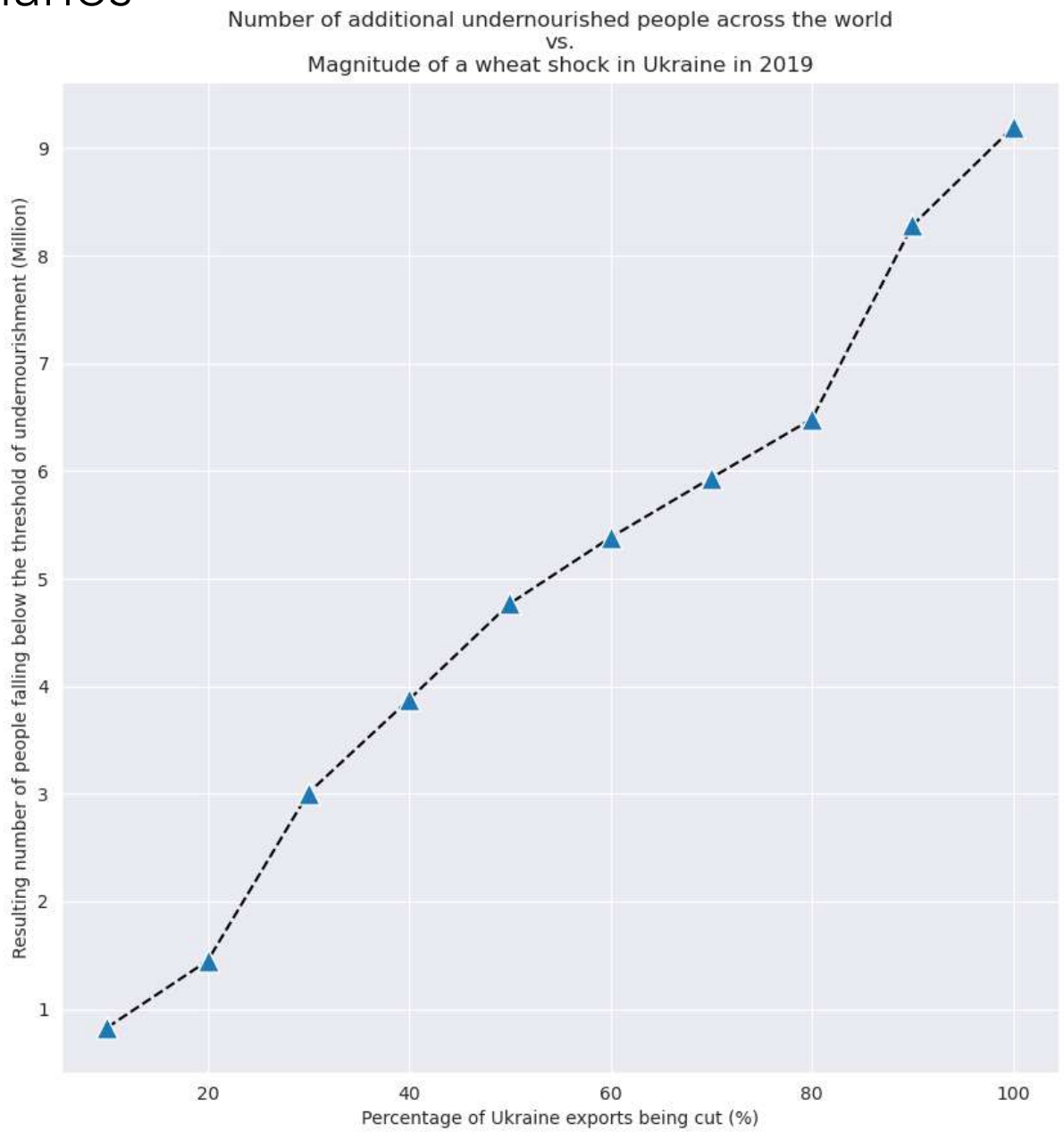
Shock simulation: 50% export decrease



Shock simulation: 50% export decrease



Other scenarios



Discussion

- For a 50% export cut from Ukraine, a total of ~5 million individuals fall under the minimum diatery energy requirement. For most affected countries indirect effects are responsible for their supply problems

- 3 different groups of countries
  - Low f_w, low C_{tot}: danger (Africa, south and central America, …)
  - Large f_w, medium C_{tot}: danger (North Africa, Eastern Europe,…)
  - Moderate f_w, large C_{tot}: out of danger (Europe, NAmerica)

- We developed a parsimonious model for shock propagation in food trade networks. This simple analysis/model helped us to point to the relevant parameters and mechanisms and could be used to test mitigation strategies

Thank you for your attention.

http://www.quanturb.com
marc.barthelemy@ipht.fr

Additional slides

Food crises

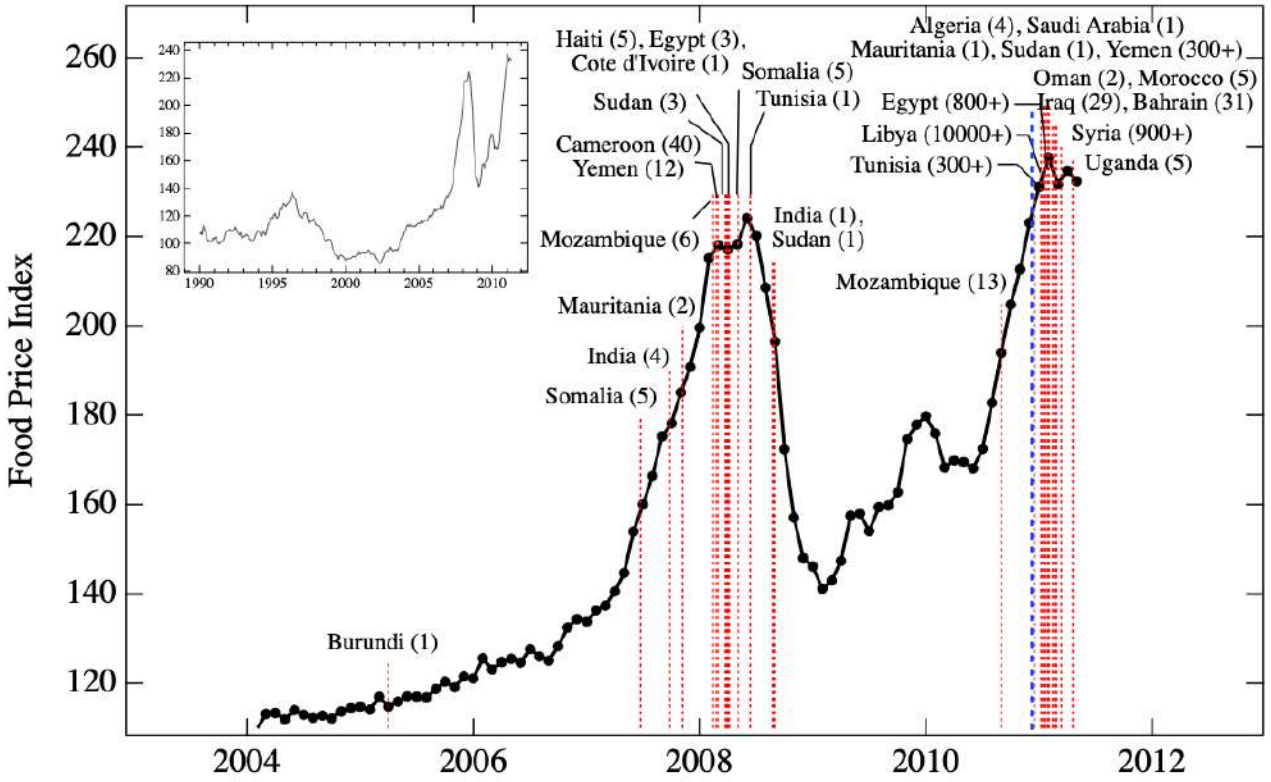
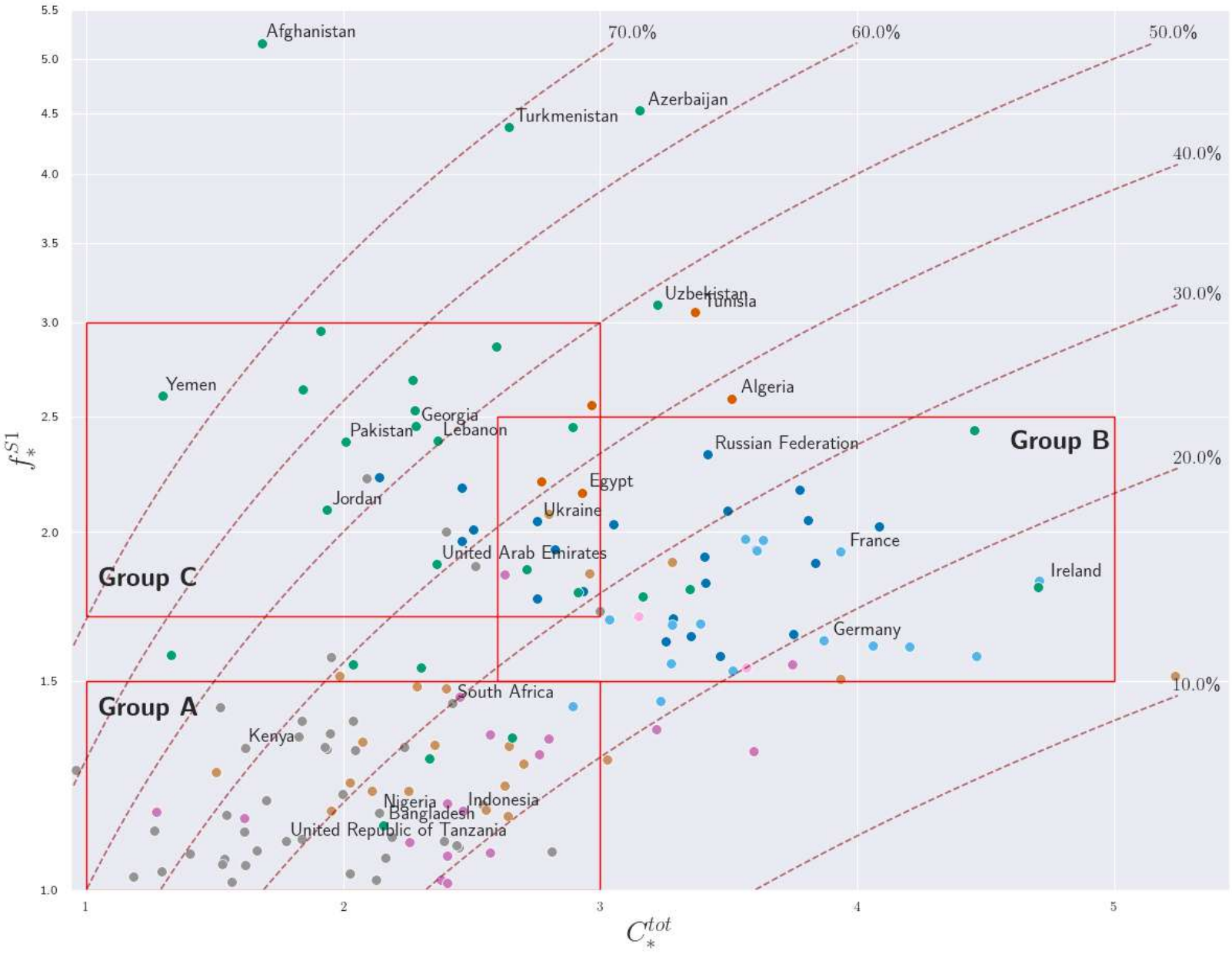


FIG. 1: Time dependence of FAO Food Price Index from January 2004 to May 2011. Red dashed vertical lines correspond to beginning dates of "food riots" and protests associated with the major recent unrest in North Africa and the Middle East. The overall death toll is reported in parentheses [26–55]. Blue vertical line indicates the date, December 13, 2010, on which we submitted a report to the U.S. government, warning of the link between food prices, social unrest and political instability [56]. Inset shows FAO Food Price Index from 1990 to 2011.

Lagi, Marco, Karla Z. Bertrand, and Yaneer Bar-Yam. "The food crises and political instability in North Africa and the Middle East." *arXiv preprint arXiv:1108.2455* (2011).


Afghanistan
Turkmenistan
Azerbaijan
Uzbekistan
Tunisia
Yemen
Algeria
Georgia
Pakistan
Lebanon
Russian Federation
Egypt
Jordan
Ukraine
France
United Arab Emirates
Ireland
Germany
South Africa
Kenya
Nigeria
Indonesia
Bangladesh
United Republic of Tanzania
Group A
Group B
Group C
70.0%
60.0%
50.0%
40.0%
30.0%
20.0%
10.0%
f_*^{S1}
C_*^{tot}
Eastern and Southern Europe
Northern and Western Europe
Americas
Oceania
Eastern and South-Eastern Asia
Southern, Central and Western Asia
Northern Africa
Africa except Northern Africa