CONNECTED WE STAND: A NETWORK PERSPECTIVE ON TRADE AND GLOBAL FOOD SECURITY

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Aims and scope

- We investigate the relationship between countries’ participation in agricultural trade and their vulnerability to external (productivity) shocks
  - We study the structural features of the web of bilateral trade flows in agricultural goods, translated into virtual water (VW) equivalent flows
  - We apply new insights from network analysis to the study of the diffusion and propagation of shocks

Why this research? Background questions
- What is the relationship between food security and international trade in food products?
- Does trade increase vulnerability to external shocks?
- Is there a trade-off between stability and trade openness?
- Has globalization of food trade made the world economy more fragile?

We contribute to the debate on the link between food security and self-sufficiency, especially under conditions of (water) resources scarcity
Vulnerability: a network perspective

- Complex network analysis is applied to the global network of VW (e.g., Konar et al, 2011, Tamea et al, 2013)
  - Topological characteristics and temporal evolution

- The global VW trade system is both interconnected and interdependent
  - Small local shocks may have a strong systemic effect, due to cascading failures
  - Greater connectivity reduces the likelihood of system failure, because shocks are more easily dissipated (Acemoglu et al. 2012)

- A series of papers by Acemoglu & co-authors (2010, 2012, 2013) emphasize the “granularity” effect and the interplay with the shock
  - Large shocks may result from amplification of small disturbances due to network topology
  - Shocks hitting central players will quickly propagate to the rest of the economy
  - The structure of the network and the nature of the (output) shocks (that is, the shape of shock distributions) are not separable
Virtual water & network analysis

- Our novel approach: we investigate whether the topological features of the VW network are such to favour shocks propagation
  - we link the topological features of the VW trade network to the resilience of the world system to external shocks

- Following Acemoglu et al. (2012):
  1. we first focus on the distribution of potential shocks, to study their interaction with the network → empirical analysis 1
  2. we then study the topology of the virtual water network and how it has evolved over the last 3 decades → empirical analysis 2
Empirical analysis 1: supply shocks

• Supply shock: agricultural production → Main purpose: detecting the frequency of large output losses, if there are “heavy tails”
  - data total agricultural production in ton/yr from the FAOSTAT database (1961–2012)
  - fit a linear trend to account for long-run productivity improvement
  - we focus on deviations: actual production relative to linear trend fitted to the data
  - only look at cases where actual production lower than expected

• We check whether the probability distribution functions display “heavy tails”: → larger probability of extreme events
  • There are some common metrics used to highlight the presence of heavy tails:
    1. % of observations larger than mean + 2 × st.dev.
    2. Obesity Index (Cooke et al 2014): if values are > 0.75 → fat-tailed distribution
    3. Mean Excess Function (MEF, Cooke et al. 2014): if it is upward sloping and/or the shape of the MEFs on aggregated data change significantly→ fat tailed distribution
- Very low fraction of observations out of "mean + 2st.dev" interval
- ObLn high but declines over time: relatively fat tails → Probability of extreme events declines over time
- MEF plots: upwardsloping, aggregation affects the shape
→ relatively heavy tails, but heaviness likely declines over time

<table>
<thead>
<tr>
<th>Year</th>
<th>% of obs out of interval</th>
<th>Obesity Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986</td>
<td>1</td>
<td>0.91</td>
</tr>
<tr>
<td>1990</td>
<td>1</td>
<td>0.91</td>
</tr>
<tr>
<td>1995</td>
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<td>0.89</td>
</tr>
<tr>
<td>2000</td>
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<td>0.89</td>
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<tr>
<td>2005</td>
<td>3</td>
<td>0.90</td>
</tr>
<tr>
<td>2010</td>
<td>2</td>
<td>0.88</td>
</tr>
</tbody>
</table>

Fig. 1. MEFs of the original sample and aggregated data set. Years 1995 (left panel) and 2010 (right panel).
Empirical analysis 2: network topology

• VW trade depicted as a weighted network
  - countries are nodes, VW flows are links, row countries are exporters, column countries identify importers
  - each cell of the square matrix of VW captures the VW flow from country i to country j
  - Here: unweighted network analysis $\rightarrow$ binary matrix (1 = flow)

• 25 VW trade matrices (1986-2010), 253 countries covered

• Common network indexes and indicators:
  - node degree: number of contacts maintained by the node
  - node strength: sum of the linked weights of the node
  - density: number of active links over the total number of possible connections
  - centrality: captures the node’s position within the network
  - assortativity: tendency of a highly connected node to be linked to other high-degree nodes
  - clustering: tendency of nodes to form tightly connected groups
The number of links almost double and the total volume of VW trade almost triples
Network density increases, moving from 20% (1986) to 33% (2010)
Negative but declining assortativity → hub-and-spoke structure
Clustering and centralization also declines over time: Peripheral countries have increased their relative importance

A fat-tailed distribution for node degree would imply the presence of a small core of very con- nected countries, featuring a much larger number of links than the rest of the nodes. Any shock affecting these central nodes would propagate easily to the rest of the network, and would not be com- pletely compensated by shocks in the opposite direction.

The VW network has been evolving toward a less centralized network

Balanced system: shocks are more quickly dissipated
The search for “fat-tails”: presence of a small core of very connected countries, featuring a much larger number of links than the rest of the nodes.

Any shock affecting these central nodes would propagate easily to the rest of the network, and would not be completely compensated by shocks in the opposite direction.

We focus on the Indegree distribution (the number of edges directed to a node) → we are concerned about “import” of external shocks.

Second-order degree: captures indirect links across countries.
Decresing values of kurtosis, skewness and Obesity Index, decreasing shapes of the MEFs

> distributions are more uniform over time, no sign of heavy tails
> the number of highly connected nodes is not larger than one would expect

Table 3
Descriptive statistics and indexes of tail-heaviness. First- and second-order indegree distributions.

<table>
<thead>
<tr>
<th>Year</th>
<th>First-order indegree</th>
<th></th>
<th></th>
<th></th>
<th>Second-order indegree</th>
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<tbody>
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<td>Kurtosis</td>
<td>Skewness</td>
<td>% out of interval</td>
<td>Obesity Index</td>
<td>Kurtosis</td>
<td>Skewness</td>
<td>% out of interval</td>
<td>Obesity Index</td>
</tr>
<tr>
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<td>0.12</td>
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<tr>
<td>2005</td>
<td>2.75</td>
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<td>0.004</td>
<td>2.4</td>
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<td>2010</td>
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<td>0.44</td>
<td>4.2</td>
<td>0.57</td>
<td>2.21</td>
<td>0.04</td>
<td>1.0</td>
<td>0.49</td>
</tr>
</tbody>
</table>

Fig. 3. MEF of the original sample and aggregated data set at the year 2000. First-order (left panel) and second-order (right panel) degree distribution.
Conclusion 1

• This work investigates the relationship between countries’ participation in international trade in agricultural goods and their vulnerability to external shocks from a network perspective.

• Our analysis reveals that:
  1. the probability of large supply shocks hitting the system is larger than one would predict under a Normal distribution, but has not increased over time.
  2. the structure of the VW network has become more balanced over time, as more countries integrate further in the world system.

→ the topological characteristics of the VW network are **not** such as to **favour the systemic risk** associated with shock propagation.

→ the world is more interconnected, but not necessarily less stable.
Conclusion 2

- Relationship trade openness - food security:
  - Trade helps to ensure that countries with limited (water) resources have access to sufficient food
  - There are fears that openness may increase the vulnerability to external shocks, making countries worse off

- Our analysis adds to this debate that:
  1. global trade cannot be regarded as a major source of instability and does not threaten food security
  2. increased globalization plays a crucial role in making the system more resilient to food crises
     - an effort to reduce the remaining trade barriers would offer new trade opportunities: as long as this also reduces heterogeneity in the network, it would have a beneficial effect on global stability
THANK YOU FOR YOUR ATTENTION

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The Obesity Index

- Developed in Cooke, Nieboer & Misiewicz (*Fat-Tailed Distributions: Data, Diagnostics and Dependence*, 2014)

- Based on the heuristic that, for heavy-tailed distributions, larger observations lie further apart than smaller observations

- \( \text{Obesity}(x) = P(x_1 + x_4 > x_2 + x_3 | x_1 \leq x_2 \leq x_3 \leq x_4) \)

Ob In = 0.5 → Normal distribution

Ob In = 0.75 → exponential distribution

Ob In > 0.75 → heavy tail in the distribution
The Mean Excess Function

- The Mean Excess Function (MEF) of a random variable $X$ gives the expected excess of $X$ over a certain threshold $u$, given that $X > u$:

$$MEF(u) = E[X - u | X > u]$$

$\rightarrow$ a fat-tailed distribution features an upward sloping MEF

- Comparing the MEF of the original dataset with the MEF computed on a dataset obtained through random aggregation of the data into groups of size $k$ (here 2 and 4) we can measure the degree of tail heaviness

$\rightarrow$ If the distribution is fat-tailed, the MEFs of the aggregated data do not change so much (and are upward sloping)
• Weighted analysis: evaluate the heterogeneity in the intensity of trade relationships
• Exterme values are increasing over time
• ObLn is high, but declining over time
• MEF first upward and then downward sloping
→ No clear evidence of fat tails, but we cannot exclude them

<table>
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<tr>
<th>Year</th>
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<th>Second-order indegree</th>
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<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
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<td>1986</td>
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<tr>
<td>2010</td>
<td>6.2</td>
<td>0.87</td>
</tr>
</tbody>
</table>

Table 4
Indexes of tail heaviness. Weighted first- and second-order indegree.

Fig. 5. MEF of the original sample and aggregated data set at the year 2000. Weighted first- (left panel) and second-order (right panel) indegree distribution.