Measuring structural resilience of economies
Globalization or deglobalization?

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Agenda

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   Motivation

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   The IO network
   Measuring structural resilience
   Measuring self-organization

Data

Results
   The structural resilience of the IO economies
   The dynamic of resilience indicators
   Globalization and deglobalization
   Resilience and self-organization

Discussion
Motivation

**Highly globalized international trade vs self-sufficiency**

- To make production processes more efficient: specialization, division of labor
- The role of intermediate goods in trade (Johnson and Noguera, 2012; Baldwin and Lopez Gonzales, 2015) and the length of GVC’s has increased (Wang et al., 2017)
- The high level of interconnectedness between countries goes hand in hand with the rapid spread of shocks (Fang et al., 2020; Iloskics et al., 2021) in which the structural properties of international linkages have a huge impact (Barrot et al., 2020; Guan et al., 2020)
- The exposure to foreign trade relations carries a high risk (Barrot et al., 2020; Bonadio et al., 2021; Fang et al., 2020; Guan et al., 2020) and the need for self-sufficiency increases (Braun et al., 2021)
- However, backshoring, nearshoring (Piatanesi and Arauzo-Carod, 2019) and for example, in the case of COVID, ”renationalizing” (Barrot et al., 2020) do not necessarily make economies less vulnerable
There is an obvious trade-off between efficiency gains from openness (highly globalized international trade) and high risks from dependence on global value chains (self-sufficiency).
Resilience

The responsiveness of countries to shocks might depend on the resilience of the countries

- Resilience could mean the ability to react to shocks (Reggiani et al., 2002; Annarelli and Nonino, 2016)

- Ecological Network Analysis (ENA) contributes to resilience research (Ulanowicz, 2009) - can also be applied to economic IO data (Kharraz et al., 2013; Fath, 2015; Chatterjee and Layton, 2020)

- A system’s (economy’s) resilience level derives from the two structural properties: efficiency and redundancy
  - None of the full efficiency and full redundancy is a good solution
  - An efficient system has only a few mutual relationships, which indicates strong specialized trade flows and corresponds to highly globalized production processes
  - A redundant system has many more similarly weak connections signaling a less specialized and embedded position of elements within the system, corresponding to a lower level of involvement within the international division of labor
### The IO network

The IO system

<table>
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<tr>
<th></th>
<th>$w_1$</th>
<th>$w_2$</th>
<th>...</th>
<th>$w_i$</th>
<th>$E_i$</th>
<th>$O_i$</th>
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<td>...</td>
<td>...</td>
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<td>...</td>
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<td>$e_j$</td>
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<td>$I_j$</td>
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<td>...</td>
<td>$l_j$</td>
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<td>0</td>
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</table>

- The rows and columns are the economic sectors
- $w_{i,j}$ shows the trade flow from sector $i$ to sector $j$
- $E_i$ is the export of sector $i$
- $O_i$ is the out of sector $i$
- $M_j$ is the import of sector $j$
- $I_j$ is the other input of sector $j$
- $i, j = 1, 2, \ldots n$
Measuring structural resilience

Based on Ulanowicz (2009) & Chatterjee and Layton (2020)

- **Total System Throughput (TST)**

  \[
  TST = \sum_{i=0}^{n+2} \sum_{j=0}^{n+2} T_{i,j} 
  \]  

- **Average Mutual Information (AMI)**

  \[
  AMI = \sum_{i=0}^{n+2} \sum_{j=0}^{n+2} \frac{T_{i,j}}{TST} \log_2 \left( \frac{T_{i,j} \times TST}{T_i \times T_j} \right) 
  \]  

  where

  \[
  T_i = \sum_{j=0}^{n+2} T_{i,j} \quad \text{and} \quad T_j = \sum_{i=0}^{n+2} T_{i,j} 
  \]

- **Shannon Index (H)**

  \[
  H = -\sum_{i=0}^{n+2} \sum_{j=0}^{n+2} \frac{T_{i,j}}{TST} \log_2 \left( \frac{T_{i,j}}{TST} \right) 
  \]
Measuring structural resilience (2)

- Degree of System Order, i.e. structural resilience indicator ($\alpha$)
  \[ \alpha = \frac{AMI}{H} \]  
  (4)

- Ecological Fitness Function ($R_{eco}$)
  \[ R_{eco} = -\left(\frac{AMI}{H}\right) \ln \left(\frac{AMI}{H}\right) \]  
  (5)

  and the maximum of $R_{eco} = 1/e = 0.368$ ($e = 2.7183$, Euler's Number)

- Fitness for Evolution ($F_s$)
  \[ F_s = -e^{\alpha^\beta} \log \left(\alpha^\beta\right) \]  
  (6)

  where $\beta$ is a coefficient, which serves to adjust the optimal $\alpha$ value
Ecological optimum for resilience on redundancy-efficiency scale

Figure 1: Resilience and redundancy-efficiency structure
An example

Figure 2: Network illustration for resilience

<table>
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<th>Network a)</th>
<th>Network b)</th>
<th>Network c)</th>
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<tbody>
<tr>
<td>$\alpha$</td>
<td>0.0722</td>
<td>0.3147</td>
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<tr>
<td>Fitness</td>
<td>0.1899</td>
<td>0.3638</td>
<td>0.3406</td>
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</table>
Self-organization

Based on Finn (1976)

- Construct Leontief-inverse matrix \( \mathbf{L} \), where \( \mathbf{I} \) is the identity matrix

\[
\mathbf{L} = (\mathbf{I} - \mathbf{W})^{-1}
\]  

(7)

- The sectoral-level cycling index \( FCI_i \)

\[
\hat{l}_i = \frac{l_{ii} - 1}{l_{ii}}
\]

\[
FCI_i = \hat{l}_i \frac{T_i}{\sum_i T_i}
\]

(8)

(9)

- The country-level cycling index \( FCI \)

\[
FCI = \sum_{i=0}^{n} FCI_i
\]

(10)
Data

- Trade flows and IO data: WIOD (Release 2016)
  - 43 countries, 56 sectors per country
  - Years: 2000-2014
  - We create domestic IO tables and sum imports, exports, other inputs and outputs into one-one column
  - Openness: the imported inputs divided by the total input, weighted by the size (total output) of the sectors

- Macroeconomic data: Penn World Tables (9.1 version)
  - GDPPC: real GDP at chained PPPs (in thousands bil. 2011 US dollar, per capita)
  - EMP: employment (in millions)
  - CAPITAL: capital stock at current PPPs (in thousands bil. 2011 US dollar)
Ecological vs. experiential (economic) optimum

Figure 3: The structural resilience of the IO economies (2014)
Figure 4: Countries’ redundancy and efficiency (2014)
The dynamic of resilience indicators

Figure 5: The evaluation of experiential (economic) optimum (2000-2014)
Test the analogy

Figure 6: The correlation between resilience indicator and openness
Table 1: Regression table for the connection between structural properties (redundancy and efficiency) and openness (the level of self-sufficiency and international trade)

<table>
<thead>
<tr>
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<th>Panel A2</th>
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<td></td>
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<td>Yes</td>
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<td>Adj. $R^2$</td>
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Table 2: Regression table for the connection between resilience and self-organization

<table>
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<tr>
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<tr>
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<tr>
<td>Country FE</td>
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Resilience and self-organization (2)

Figure 7: The optimal level of self-organization
Optimal self-organization

Figure 8: The level of countries’ self-organization (2014)
Discussion

- Optimum: ecological vs. experiential
  - Fath (2015) discussed in detail
  - Higher redundancy: sectoral IO data are very aggregated data - denser network
  - Experiential optimum: not stable - weaken the barriers

- Self-organization
  - Openness influences negatively the cycling index (Braun et al., 2021)
  - Countries with effective (redundant) structure and low (higher) cycling - reduce (increase) the level of international trade
  - Countries with redundant structure and low cycling - deeper structural changes are needed

- Policy implications
  - The results shed light on which country has to reduce the exposure of international trade and which country has to increase the specialization
  - Where is it necessary to strengthen/weaken the level of self-organization?
Thank you for your attention!

All comments and questions are welcome!

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