Influence of petroleum and gas trade of Russia on EU economies from the Google matrix analysis of UN COMTRADE data

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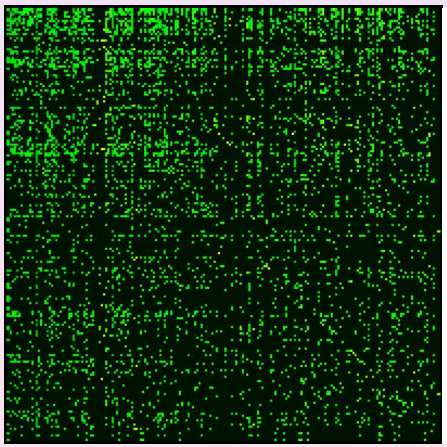
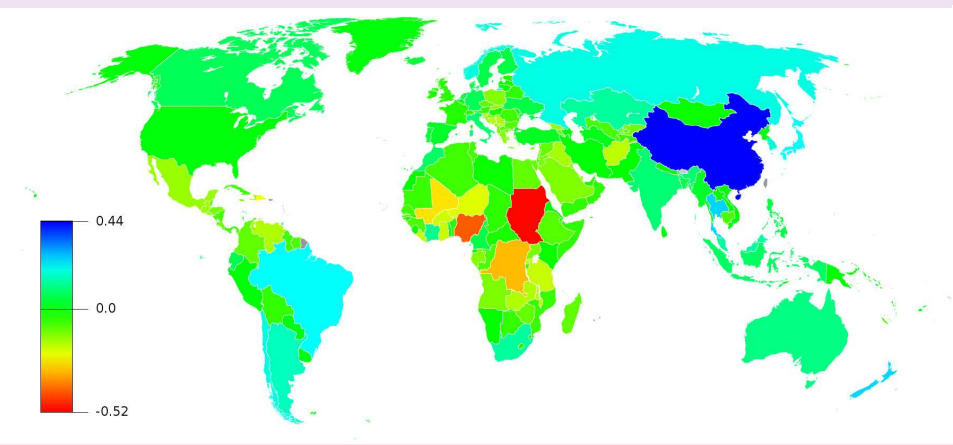
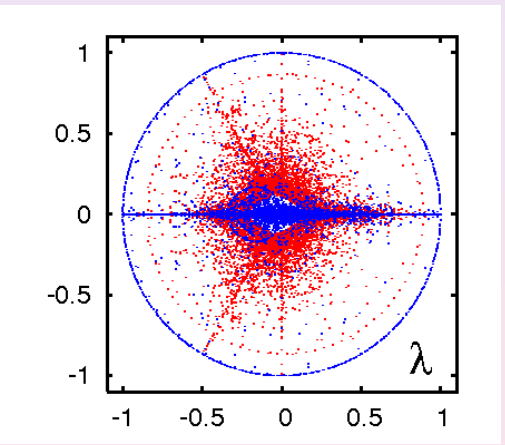




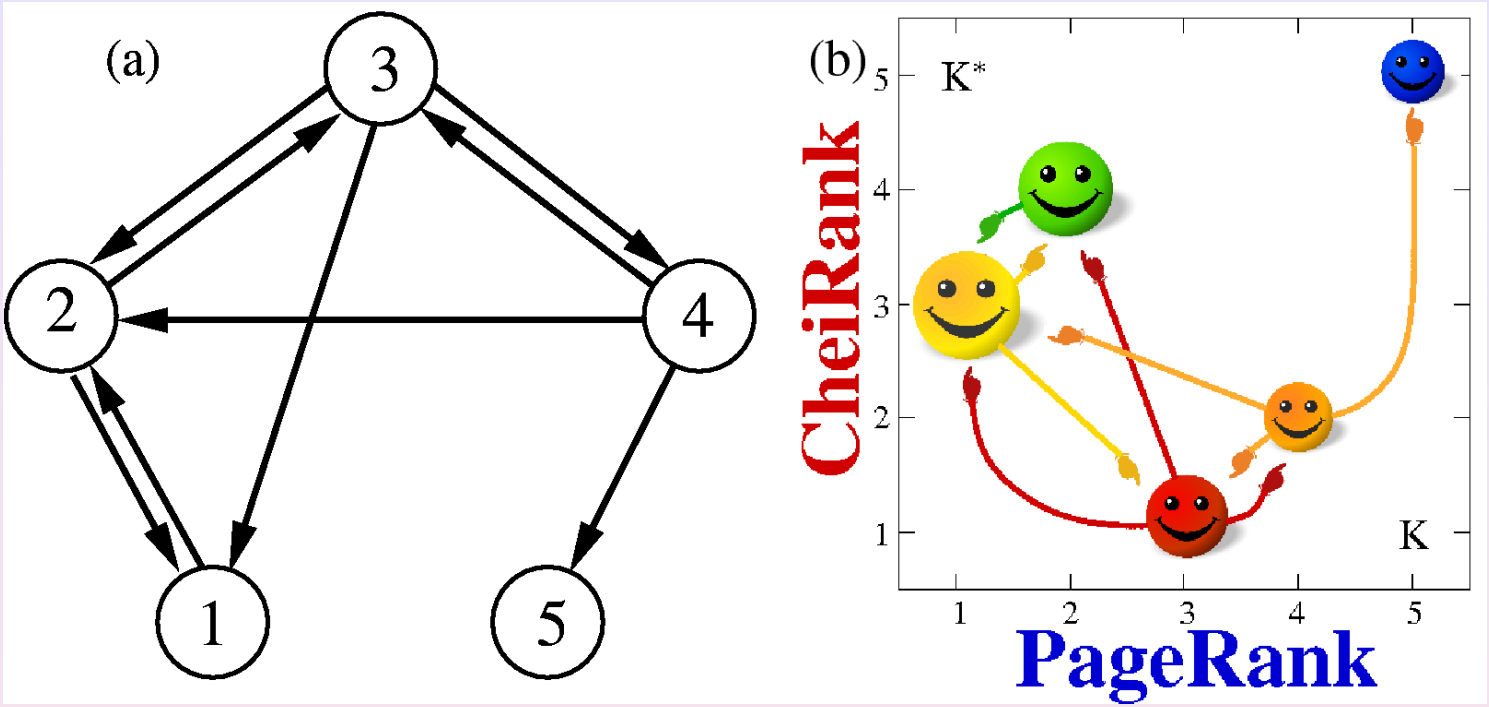


* Markov (1906) → Brin and Page (1998) → Google matrix and search engines
* Applications: multiproduct world trade networks (UN COMTRADE), Wikipedia Ranking of World Universitis (WRWU) ...

Support: EC FET Open NADINE (2012-2015), APLIGOOGLE-CNRS (2016-2017), LABEX NEXT (2017-2020) + thanks to UN COMTRADE

Google matrix construction rules

Markov chains (1906) and Directed networks



For a directed network with N nodes the adjacency matrix $\mathbf{A}$ is defined as $A_{ij} = 1$ if there is a link from node j to node i and $A_{ij} = 0$ otherwise. The weighted adjacency matrix is

$$S_{ij} = A_{ij} / \sum_k A_{kj}$$

In addition the elements of columns with only zeros elements are replaced by $1/N$.

Google matrix construction rules

Google Matrix and Computation of PageRank

$\mathbf{P} = \mathbf{SP} \Rightarrow \mathbf{P}$= stationary vector of $\mathbf{S}$; can be computed by iteration of $\mathbf{S}$.

To remove convergence problems:

- Replace columns of 0 (dangling nodes) by $\frac{1}{N}$:

$$S = \begin{pmatrix} 0 & 1/2 & 1/3 & 0 & 1/5 \\ 1 & 0 & 1/3 & 1/3 & 1/5 \\ 0 & 1/2 & 0 & 1/3 & 1/5 \\ 0 & 0 & 1/3 & 0 & 1/5 \\ 0 & 0 & 0 & 1/3 & 1/5 \end{pmatrix} \qquad S^* = \begin{pmatrix} 0 & 1/3 & 0 & 0 & 0 \\ 1/2 & 0 & 1/2 & 0 & 0 \\ 1/2 & 1/3 & 0 & 1 & 0 \\ 0 & 1/3 & 1/2 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

- To remove degeneracies of $\lambda = 1$, replace $\mathbf{S}$ by **Google matrix**
  $\mathbf{G} = \alpha\mathbf{S} + (1-\alpha)\frac{\mathbf{E}}{N}$; $GP = \lambda P$ => Perron-Frobenius operator
- α models a random surfer with a random jump after approximately 6 clicks (usually $\alpha = 0.85$); PageRank vector => P at $\lambda = 1$ ($\sum_j P_j = 1$).
- CheiRank vector P^*: $G^* = \alpha\mathbf{S}^* + (1-\alpha)\frac{\mathbf{E}}{N}$, $G^*P^* = P^*$
  ($\mathbf{S}^*$ with inverted link directions) $\rightarrow K - K^*$ PageRank-CheiRank index
  Chepelianskii arXiv:1003.5455 (2010) ...

Computation algorithms

* PageRank vector by power iteration:
multiplication of initial random vector by G matrix; convergence to $\lambda = 1$ eigenvector as α^t, about $t = 200$ iterations are enough for double precision convergence (all eigenvalues have $|\lambda| \leq \alpha < 1$ except $\lambda = 1$);
on average there are only about 10-20 nonzero links for each node (about 20 multiplications of vector by a line of matrix)
$\rightarrow$ small-world structure of real networks or six degrees of separation (Milgram Psychology Today (1967));
* Arnoldi algorithm: eigenvalues with largest $|\lambda|$ and related selected eigenvectors corresponding to quasi-isolated communities.
* REGOMAX Reduced Google matrix: description of interactions of subset of selected nodes in a huge network
* GPU codes for reduced Google matrix: 100 times acceleration compared to one-processor computer; collaboration with
Denis Demidov (Russian Academy of Sciences, Kazan; see https://github.com/ddemidov for GPU oriented codes)
What is the central bank of Wikipedia ?
by D.Demidov, K.M.Frahm, DS Physica A v.542, p.123199 (2020)

Directed networks analyzed

* Wikipedia editions: EN (2009) $N = 3282257$;
24 editions Wiki2013: $N = 4212493$ EN, $N = 1532978$ DE, $N = 1352825$ FR
24 editions Wiki2017: $N = 5416537$ EN, $N = 2057898$ DE, $N = 1866546$ FR

* Entier Twitter (2009): $N = 41$millions

* Entier Phys. Rev. citation network(1893-2009): $N = 460422$

* World Trade Network (WTN) from UN COMTRADE about 50 years: $N = 227$ for all commodities; multiproduct trade with 61 products $N = 13847$; available with 5000 products and $N \approx 1 million$

* Bitcion network transactions (beginning 2009 till April 2013): $N = 6297009$

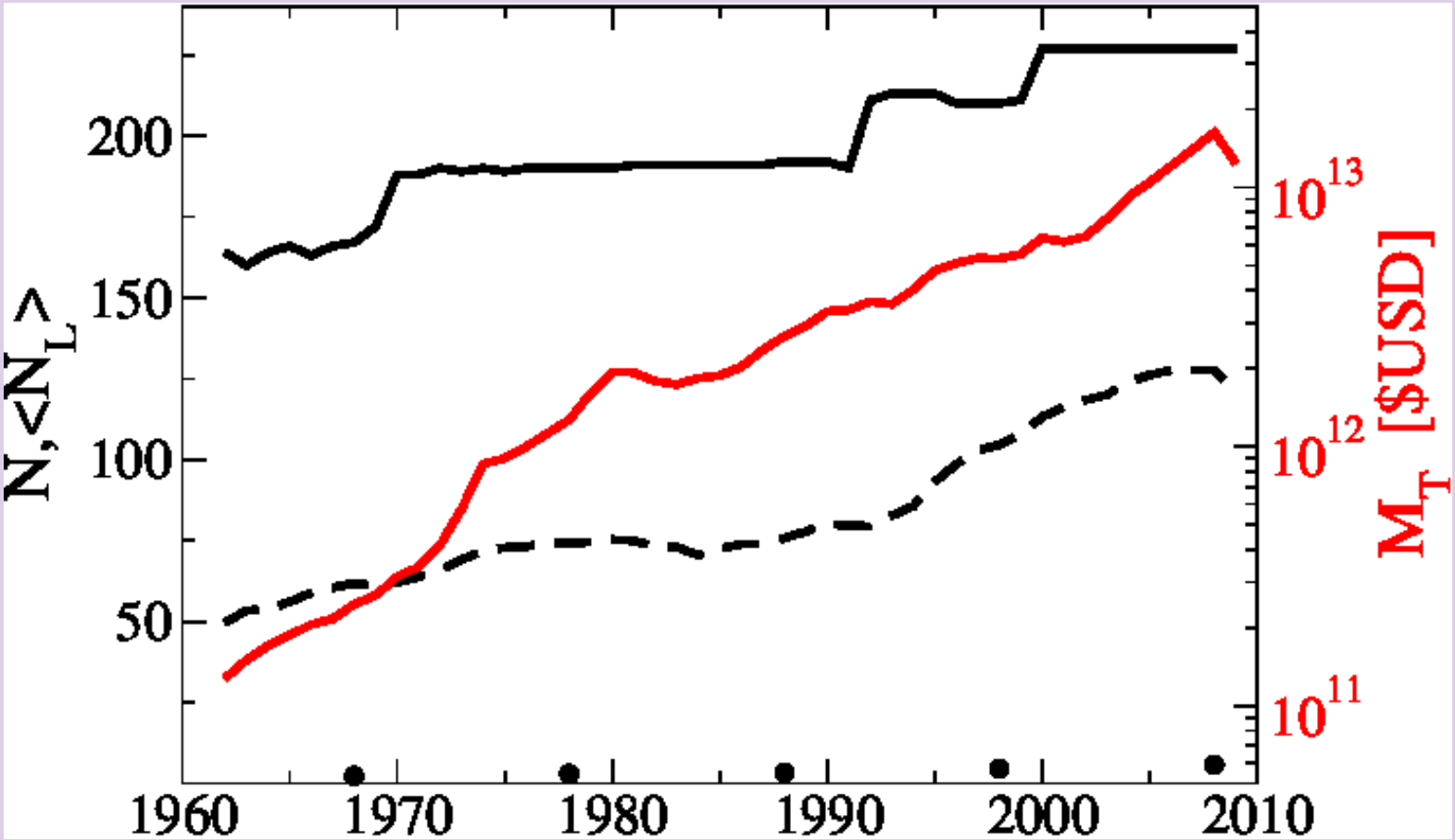
* Linux Kernel network: $N = 285509$

* UK university networks till 2006: U Oxford, Cambridge $N \approx 200000$

* Network of protein-protein interactions for cancer: $N \approx 3000$

see Ermann, Frahm, DS Rev Mod Phys (2015)
ALL PUBS: http://www.quantware.ups-tlse.fr/dima/subjgoogle.html

World trade network (WTN) of United Nations COMTRADE 1962-2010

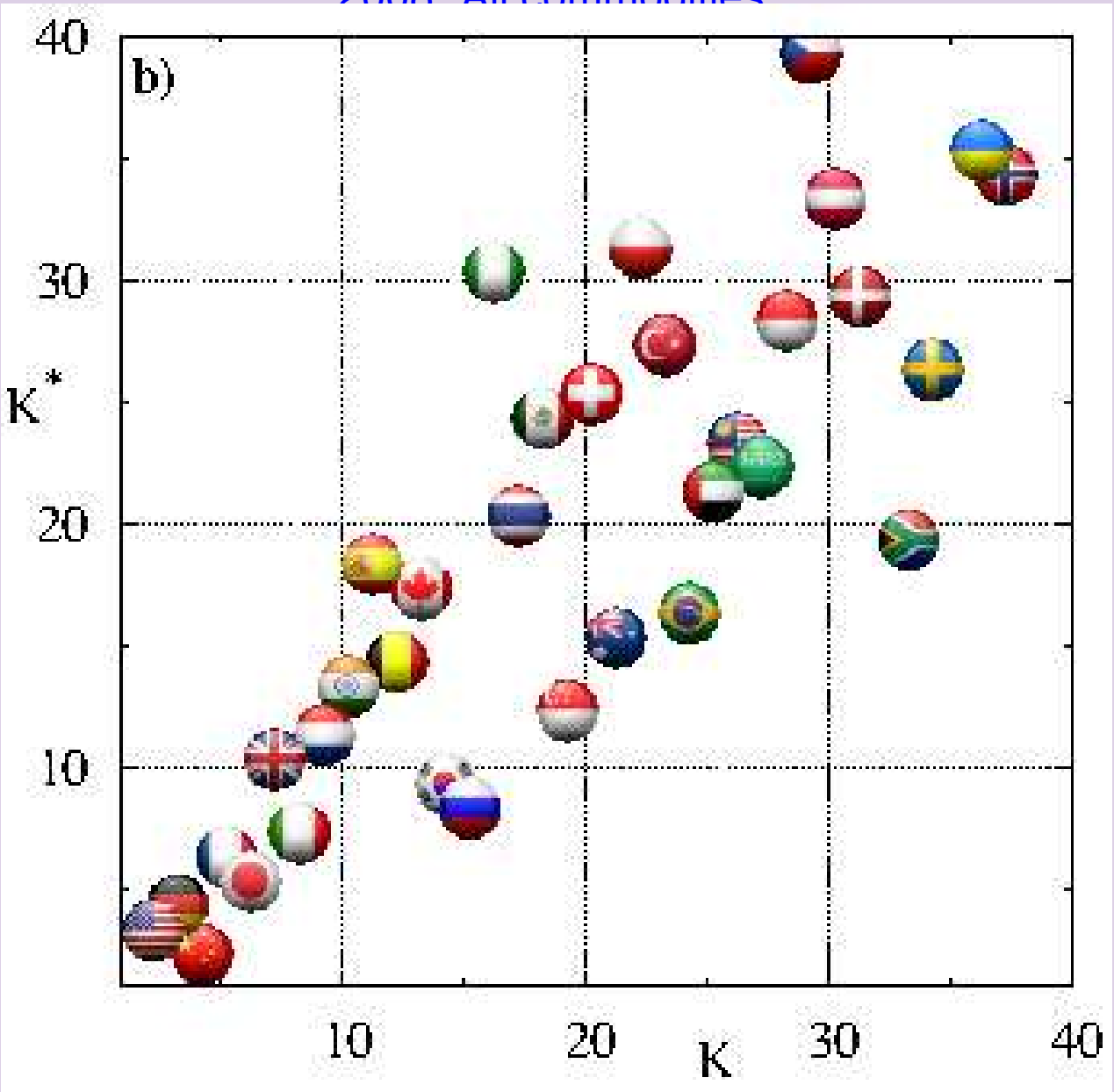


Number of countries (black), links (dashed/points) and mass volume in USD (red)

Leonardo Ermann, DS arxiv:1103.5027 (2011); EPJB (2015)

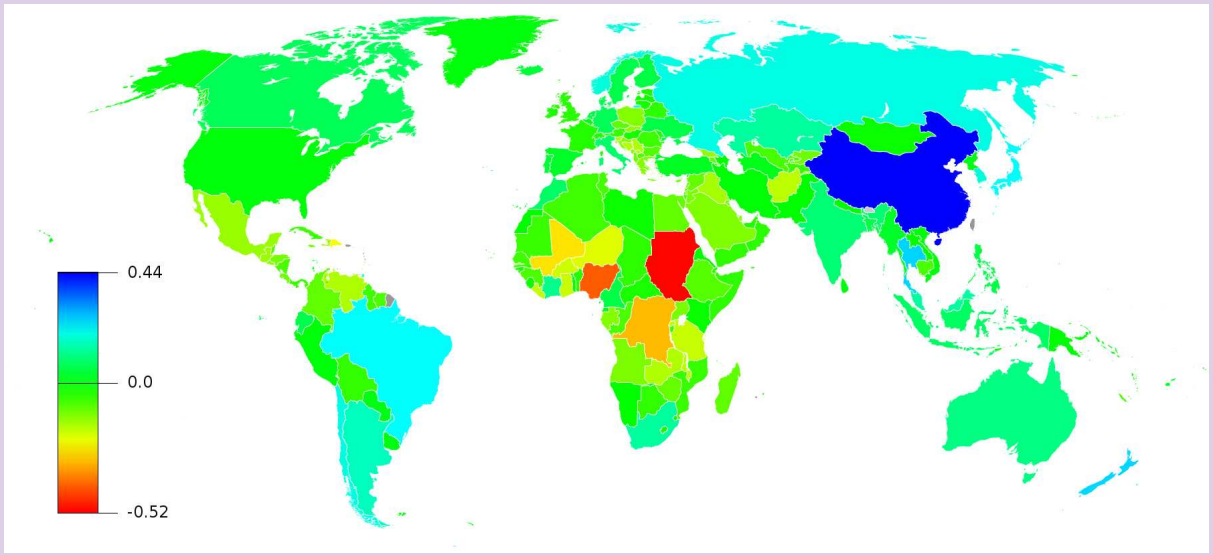
Ranking of World Trade

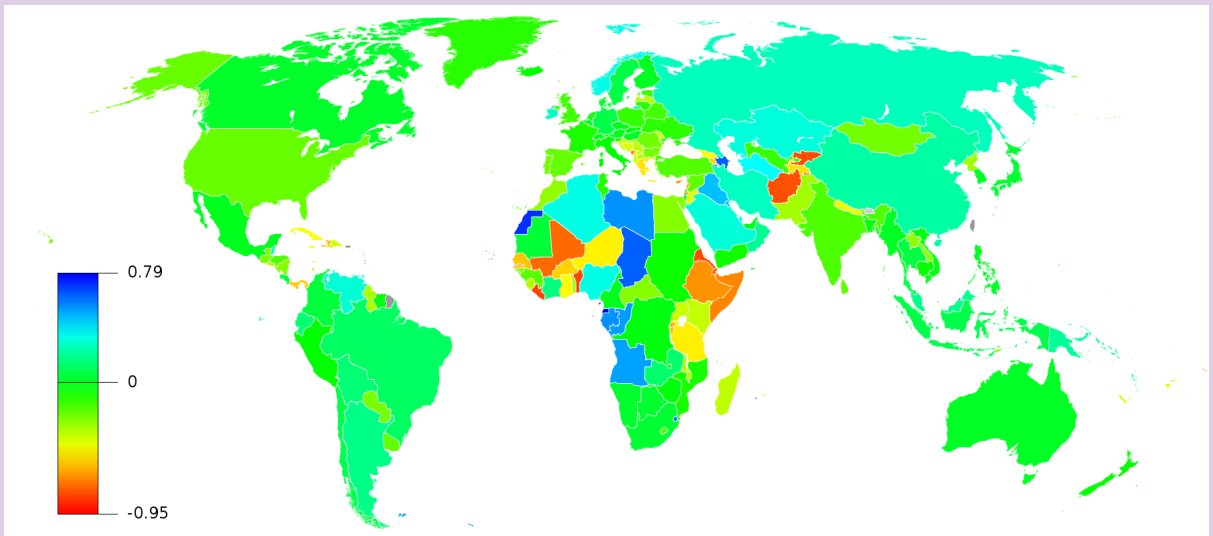
2008: All commodities



CheiRank-PageRank balance (2008)

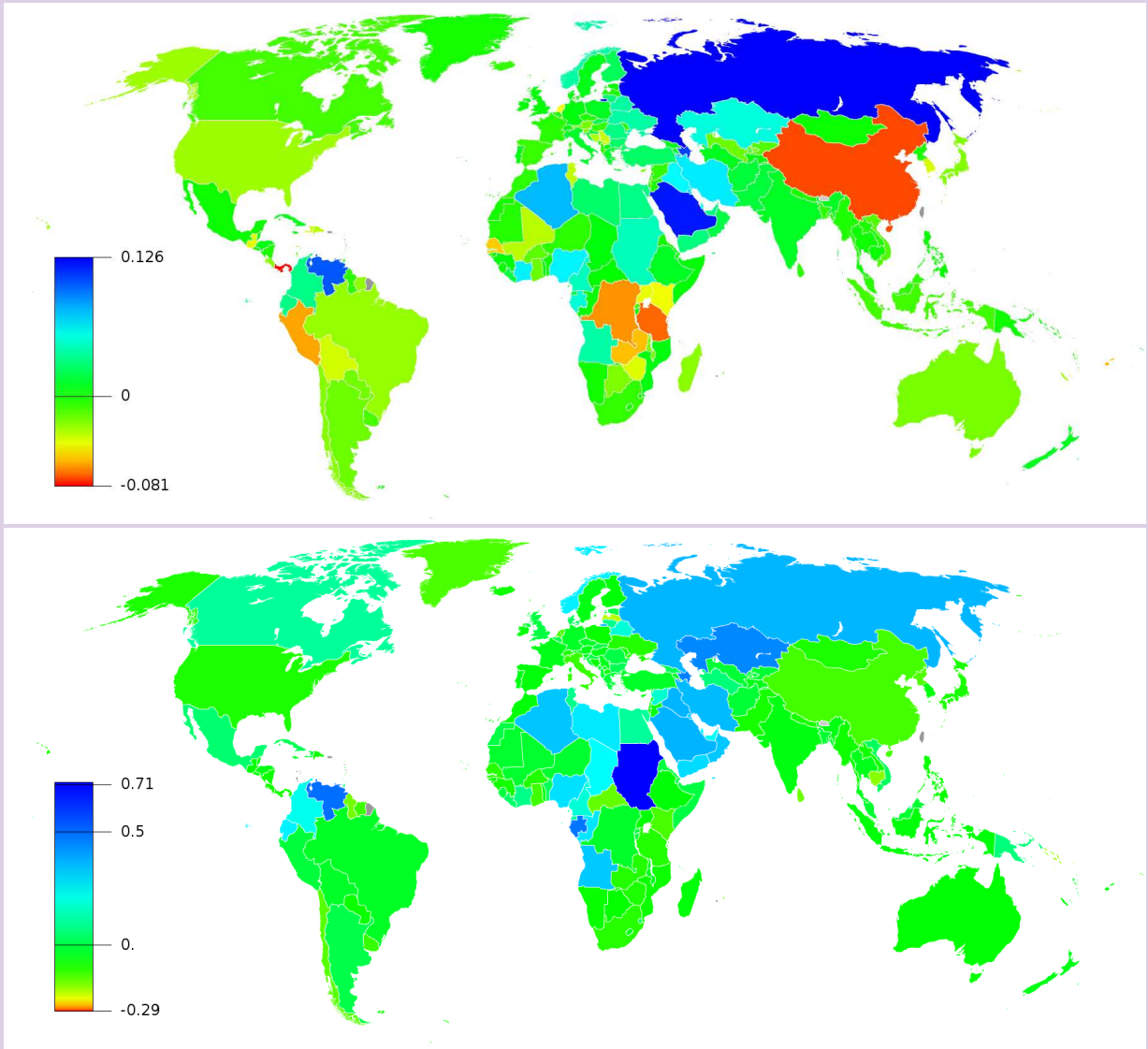
$B_c = (P_c^* - P_c)/(P_c^* + P_c)$ (top - CheiRank-PageRank;
bottom -Export-Import volume; multiproduct world trade
$N_c = 227 countries$, $N_p = 61 products$, $N = 13847$ ==> UN COMTRADE)





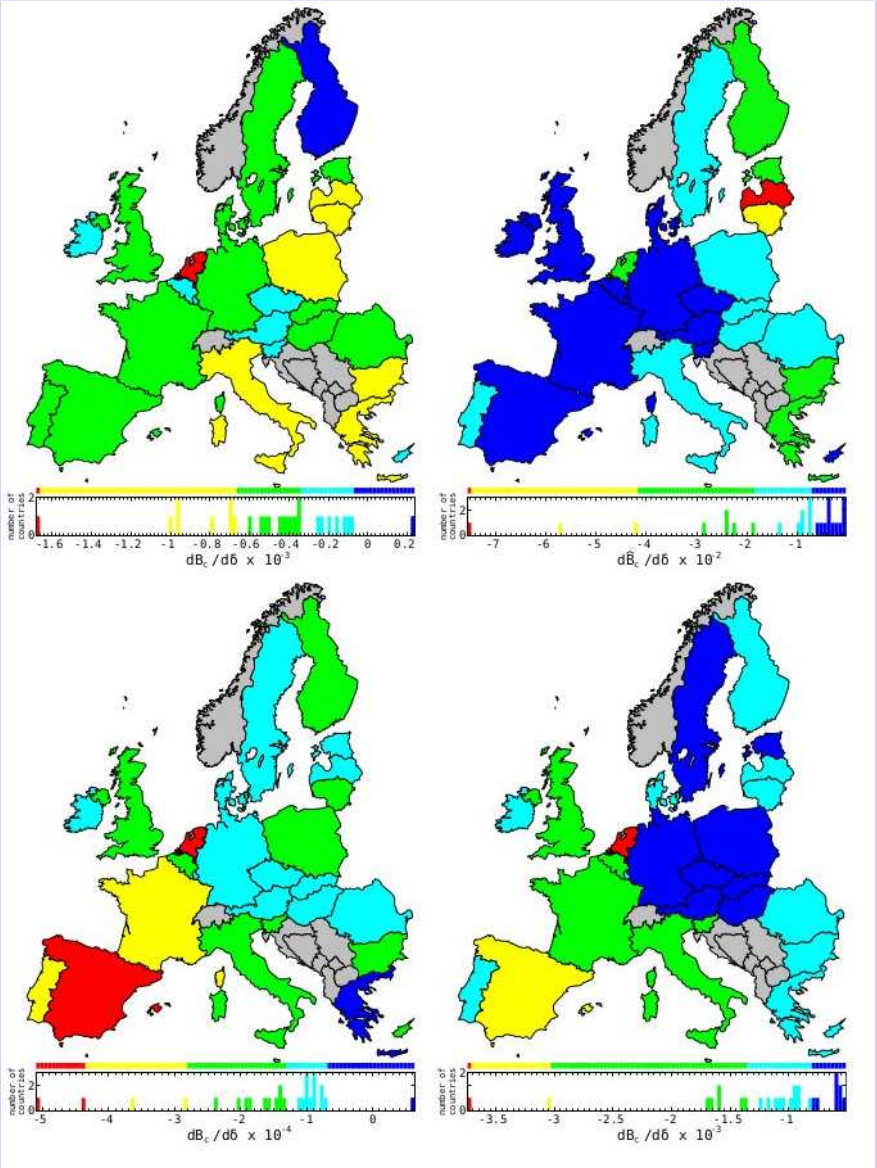
Sensitivity to petrolem price (2008)

$B_c = (P_c^* - P_c)/(P_c^* + P_c)$, color => $dB_c/d\delta_{petroleum}$)

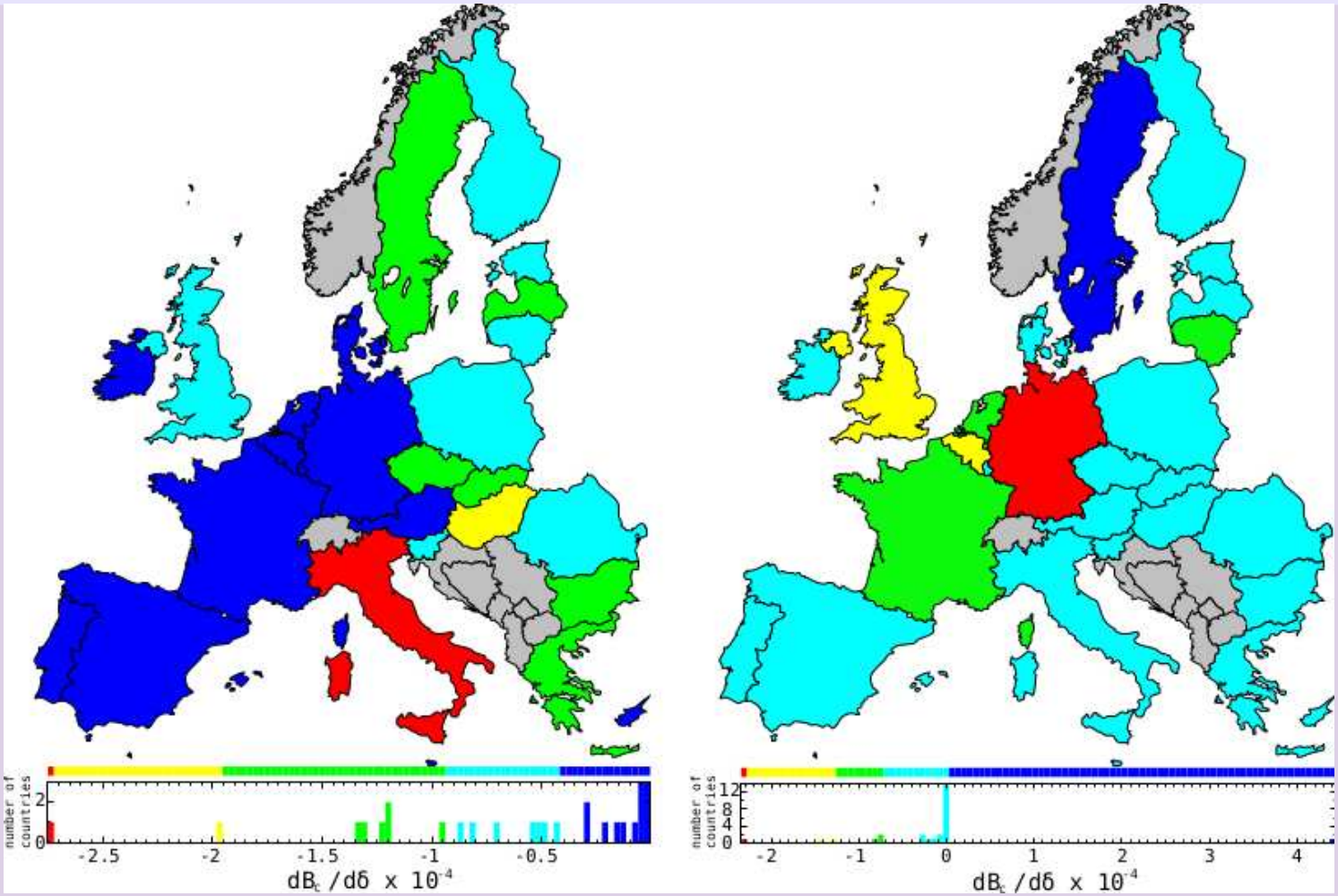


EU sensitivity to petrolem price (2016)

Top: RU (Page-Chei-Rank - left); RU (Import-Export - right)
Bottom: Saudi Arabia (left), USA (right) (Page-Chei-Rank)

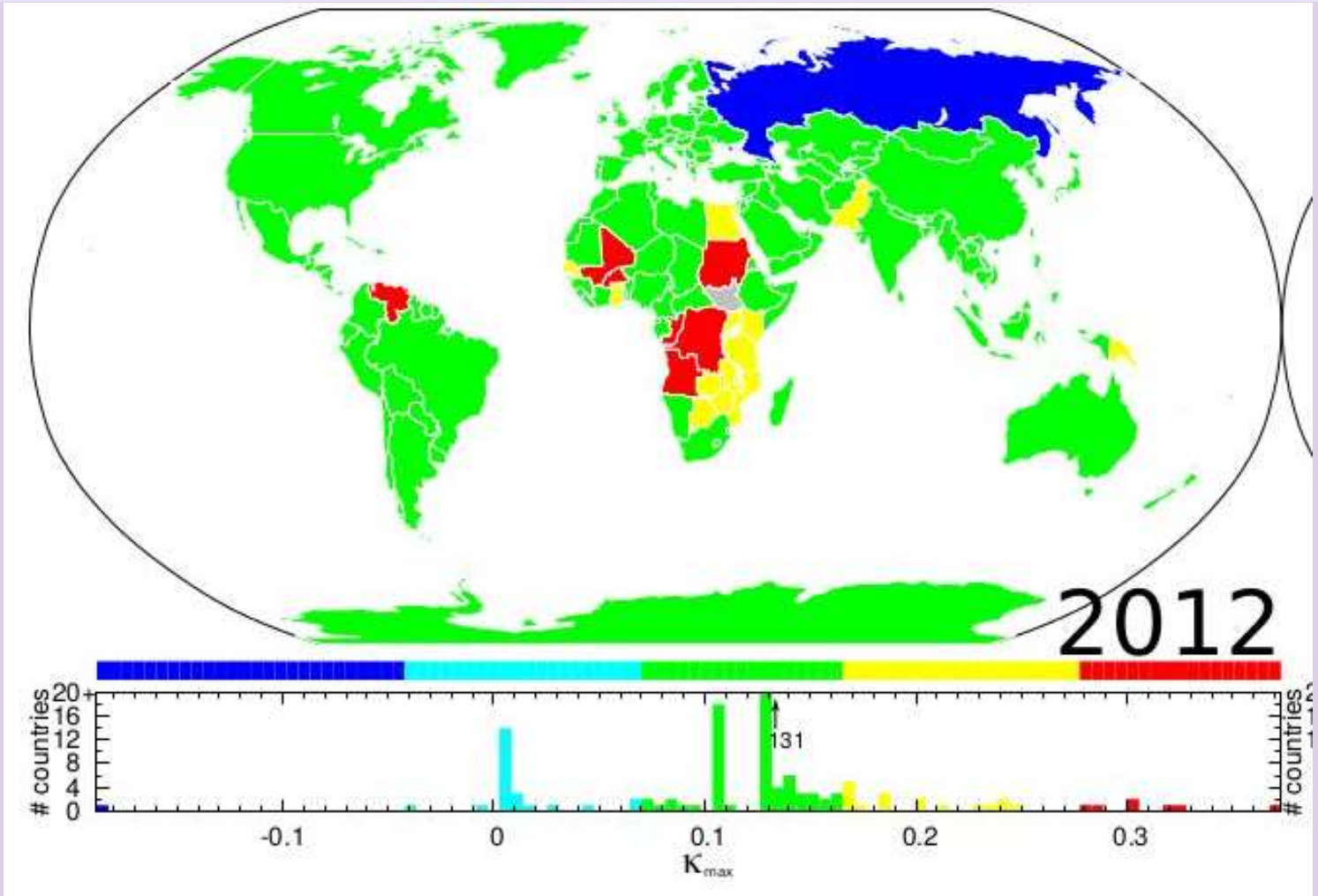


EU sensitivity to gas price (2016)



Balance derivative $dB_c/d\delta$ from gas price increase from Russia (left), Norway (right)

Model of crisis contagtion in the world trade network of (UN COMTRADE 2012)



Blue - stable; red - bankruptcy

Main references

Ref.1 L.Ermann and D.L.Shepelyansky, "Google matrix of the world trade network", Acta Physica Polonica A v.120(6A), pp. A158-A171 (2011)

Ref.2 L.Ermann and D.L.Shepelyansky, "Google matrix analysis of the multiproduct world trade network", Eur. Phys. J. B v.88, p.84 (2015)

Ref.3 C.Coquide, L.Ermann, J.Lages and D.L.Shepelyansky, "Influence of petroleum and gas trade on EU economies from the reduced Google matrix analysis of UN COMTRADE data", Eur. Phys. J. B v.92, p.171 (2019)

Ref.4 C.Coquide, J.Lages and D.L.Shepelyansky, "Crisis contagion in the world trade network ", submitted to Springer Series 17 Feb (2020) (arXiv:2002.07100[q-fin.TR])

Articles available at
http://www.quantware.ups-tlse.fr/dima/subjgoogle.html