

Supplementary Information

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S1. Nestedness measurement---NODF

Many recent studies have enlightened the nested pattern of ecological and economic systems [1-5]. The nested organization means that the network consists of sets of generalist nodes and sets of specialist nodes. The specialists interact only with a small subset of generalist nodes, while the generalists interact with (almost) all other nodes in the network. Nestedness is a statistical property of interaction data presented in matrix form. We measure the nestedness of the matrices using the NODF metric [1]. In the beginning of calculation, the rows and the columns of a matrix are swapped and rank-ordered by the sum of the presences in each of these rows and columns, respectively. The transformed matrices are then ready to be processed by the flowing equation.

$$NODF_{ij} = \sum_{i < j} \begin{cases} 0, & \text{if } k_i = k_j \\ \frac{\sum_l M_{il} M_{jl}}{\min(k_i, k_j)} & \text{otherwise} \end{cases}$$

$$NODF = \frac{\sum_{i < j} (NODF_{ij}^{row} + NODF_{ij}^{column})}{\frac{n(n-1)}{2} + \frac{m(m-1)}{2}};$$

Here k_i is the number of 1 in i^{st} row i.e. degree. The NODF measure takes values between 0 (unnested) and 1 (perfectly nested). Fig.S1 gives an example of calculation of nestedness which is from ref [1].

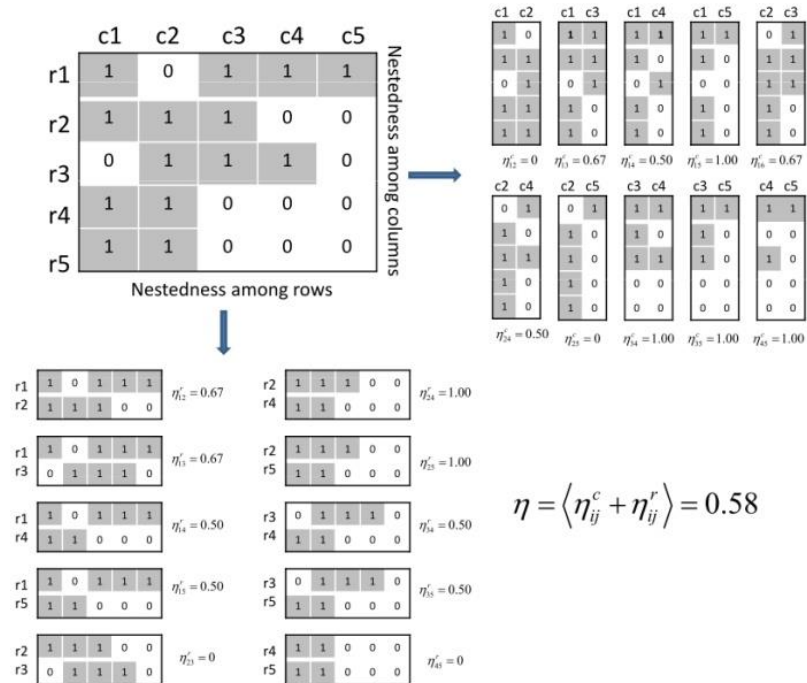


Fig. S1 The calculation of nestedness

S2. Data sets

We collect trade datasets which are available from UN comtrade [6]. There is also an alternative data source from BACI [7](BACI data can be directly downloaded from [8]). These datasets consist of imports and exports both by destination as seen in Table S1. All of the product information is classified by Standard International Trade Classification (SITC). There are four levels namely Section, Division, Group, Subgroup in SITC. We take an example as shown in Fig. S1 from ref [9]. We respectively label the four digits like S8, D87, G874, SG8744. The detailed name of products can be queried from ref [4]. The BACI datasets and UN datasets are used in context and SI to support our conclusions. The basic information of data sets is seen in Table S2.

Table S1. Data formats

Year	Reporter	Partner	product	volume
2000	CHN	USA	FootWear	\$10,000,000
2011				
1976				
2015				
.....

Table S2. data set information

source	Time span	classification	digits	country	products
UN	1976-2015	SITC Rev2	4	261	786
BACI	1962-2014	SITC Rev2	4	261	786

Detailed structure and explanatory notes

SITC Rev.4 code 874.4

Structure

Hierarchy

- Section: 8 - Miscellaneous manufactured articles
- Division: 87 - Professional, scientific and controlling instruments and apparatus, n.e.s.
- Group: 874 - Measuring, checking, analysing and controlling instruments and apparatus, n.e.s.
- Subgroup: **874.4 - Instruments and apparatus for physical or chemical analysis (e.g., polarimeters, refractometers, spectrometers, gas or smoke analysis apparatus); instruments and apparatus for measuring or checking viscosity, porosity, expansion, surface tension or the like; instruments and apparatus for measuring or checking quantities of heat, sound or light (including exposure meters); microtomes**

Fig. S2 The content is from <https://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=28>).

S3. Build complex networks according to trade interactions.

1. For a target product p , we can select the trade interactions just contained the target product trade information and then build a matrix $M_{cc'}^p = \{v_{cc'}^p\}$, which can be expressed as the country c exports the target product p to the country c' .
2. It is necessary to check a trade interaction whether performs revealed comparative advantage [5]. We need to estimate whether a trade interaction between two countries is significant in the trade network of the given product, and can calculate whether a trade interaction's share of a country's trade, is larger or smaller than the country's share of the entire whole market. Mathematically

$$RCA_{cc'}^p = \frac{v_{cc'}^p / \sum_c v_{cc'}^p}{\sum_{c'} v_{cc'}^p / \sum_c \sum_{c'} v_{cc'}^p},$$

where $v_{cc'}^p$ is equal to the dollar volume of a trade interaction between country c and country c' . The natural cutoff used to determine whether a trade interaction has revealed comparative advantage which is $RCA \geq \lambda$. We can therefore construct the binary country-country matrix from the RCA matrix, if we consider,

$$a_{cc'}^p = \begin{cases} 1 & \text{if } RCA_{cc'}^p \geq \lambda \\ 0 & \text{if } RCA_{cc'}^p < \lambda \end{cases}$$

Thus, we can construct a directed network for a given product from view of network science. The nodes represent countries, and then if $a_{cc'}^p = 1$ there is a link is connected between two countries c and c' . The same steps for each product, we can build multilayer networks.

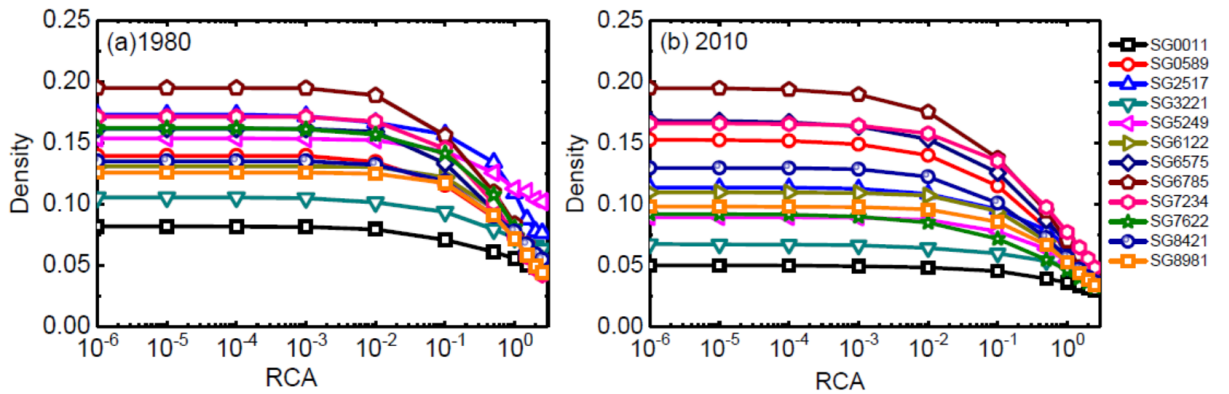


Fig. S3 The network is constructed by different RCA thresholds. We analyze the four level products in 1980 and 2010. Different curves present different product networks built by RCA. Network size is defined as the length of column multiplied by the length of row in input matrix. The given network has M links, then network density is the total number of links divided by network size.

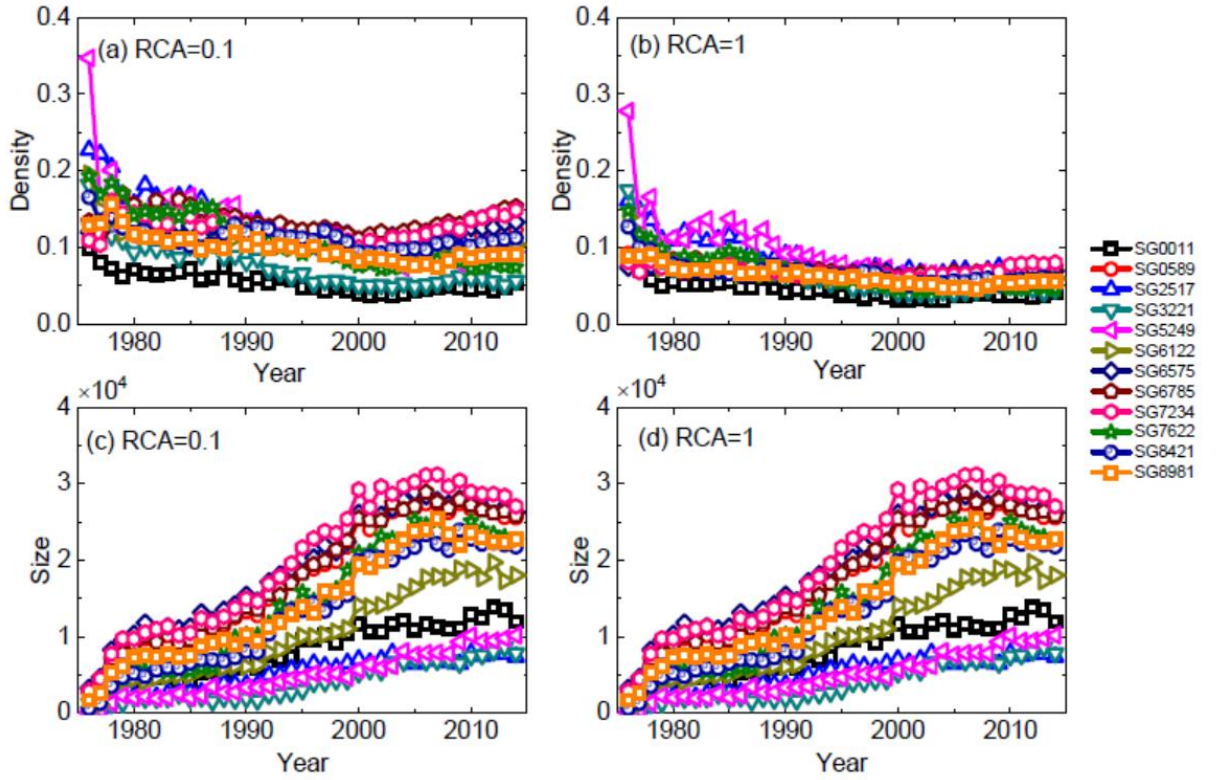


Fig. S4 Density and size evolve with time from 1976 to 2014 when $RCA=0.1$ and $RCA=1$. The density of network keeps stable situation from 1976 to 2014, the size of network increases with year. Network size is defined as the length of column multiplied by the length of row in input matrix. The given network has M links, then network density is the total number of links divided by network size.

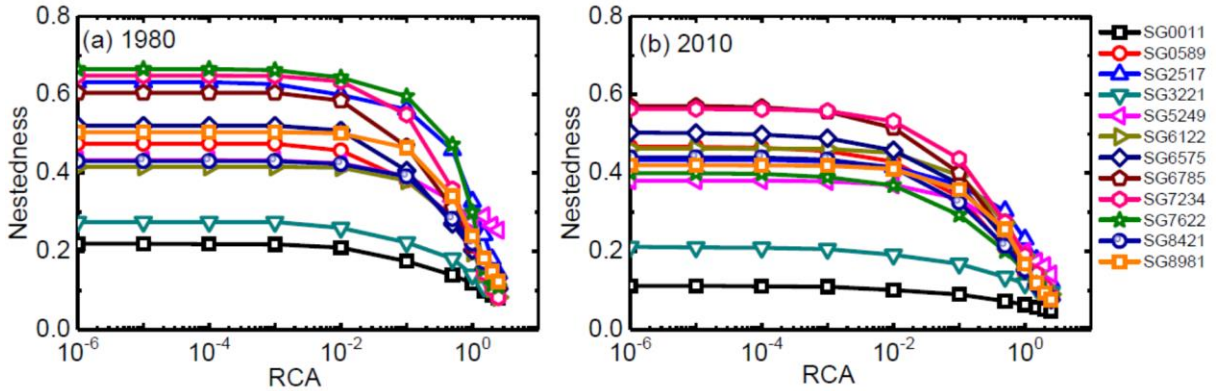


Fig. S5 Association between RCA and nestedness. The nestedness does not change when RCA is more than 0.01.

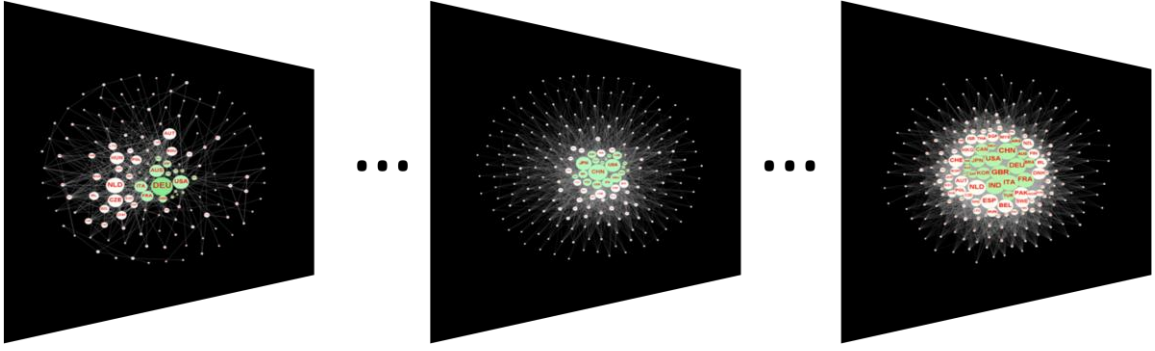


Fig. S6 Three representations of world trade networks which are corresponding to the network of Bovine, Motorcycles, and Medical Instruments. Node represents country, and link represents trade interaction between two countries. The size of node indicates the out degree that the number of links the node points to. The green nodes stand for 20 major economies (i.e. G20) except EU.

S4 Null models

We use two null models to check the significant nestedness of the input matrix[10]. The first null model conserves the network size and density. The second null model not only preserves the network size and density, but also keeps node degree.

- (1) (Swappable_Swappable) The “swappable rows, swappable columns” (SS) null model conserves matrix dimensions (numbers of rows and columns) and fill. It works by shuffling elements at random within the matrix; however, it differs in that degenerate matrices (those containing rows/columns with no connections) are not permitted. The detailed form as follows,

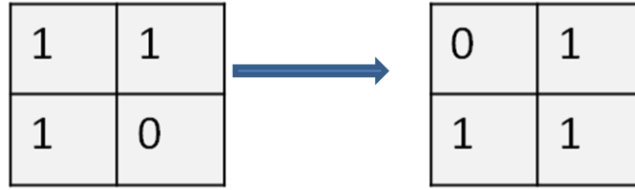


Fig. S7 The “swappable rows, swappable columns” (SS) null model

- (2) (Fixed indegree_Fixed outdegree) The “fixed in-degree, fixed out-degree” (FF) null model has subsequently been a popular choice for application to the nested networks, which preserves the degree distribution of the original network. The two links is randomly rewired but preserves the degree of the involved four nodes. This null model not only conserves the network density, but also fix degree of each nodes. The random rewired process described as,

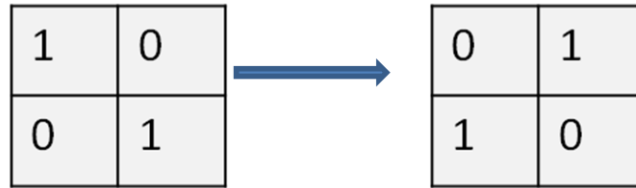


Fig. S8 The “fixed in-degree, fixed out-degree” (FF) null model

S5 Degree-degree correlation of nested networks

A network exhibits nestedness if the neighborhood of a node is contained in the neighborhoods of the nodes with higher degrees [10,11]. The topology of this network is highly disassortative since high degree nodes are disproportionately connected to low degree nodes and vice versa. We use degree-degree correlation to measure the disassortative[12,13] and detailed illustrations seen in Fig.S9.

$$r = \frac{\sum_i k_i^\alpha k_i^\beta - M^{-1} \sum_i k_i^\alpha \sum_{i'} k_{i'}^\beta}{\sqrt{\left[\sum_i (k_i^\beta)^2 - M^{-1} (\sum_i k_i^\beta)^2 \right] \left[\sum_i (k_i^\alpha)^2 - M^{-1} (\sum_i k_i^\alpha)^2 \right]}},$$

Where, Let $\alpha, \beta \in \{in, out\}$ index the degree type. k_i^α and k_i^β be the α - and β -degree of the source node and target node for the i th edge. We use methods in ref [13] to measure the assortative.

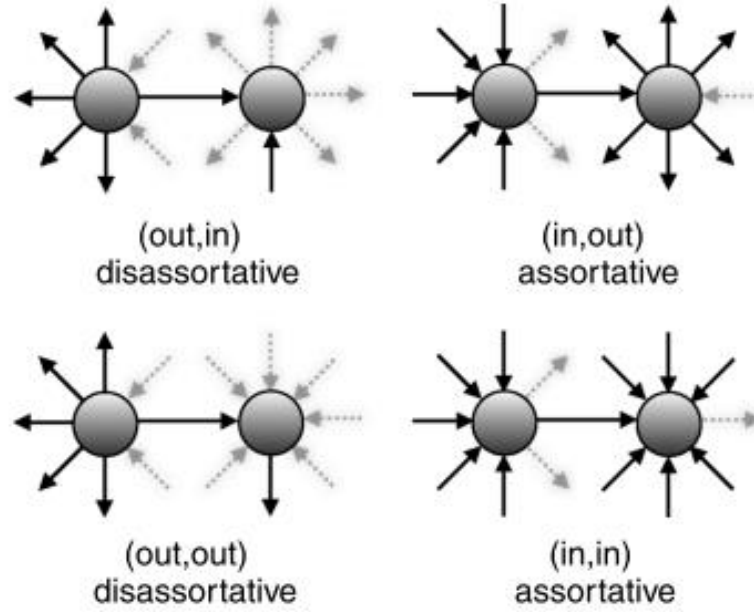


Fig. S9 The four degree-degree correlations in directed networks. The figures are from ref [13].

Reference

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