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This idea of synchronization seems interesting. How one large node effects the other nodes.

Complexity and synchronization of the World trade Web

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Abstract

The complex topology of a network determines its dynamics. The world economy is now internationally connected through a globalization process of trading. The complex dynamical behaviors of the world economy have been studied as a dynamical system, but there does not seem to be any consideration of the effect of dynamics on the world trade network. In this paper, we attempt such a study and present the scale-free features of the degree distribution, as well as wealth and resource distributions on the World Trade Web (WTW). Moreover, the synchronization phenomenon of economic cycles on the WTW due to its scale-free features is discussed in detail.

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1. Introduction

Recently, complex web-like structures in describing a wide variety of systems have been studied, and more and more natural as well as artificial networks have been

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investigated [1,2,4–6,14], due mainly to the powerful computer advances. Significant discoveries have been found, showing differences from the random graph theory, which was developed by Erdös and Rényi [7,8] and has dominated the network studies for nearly half of a century. One of the significant discoveries is that many real-life complex networks show their degree distributions to be scale invariant and in a power-law form [1,3–6,14]. Such scale-free networks exhibit many unique characteristics contrasting to those of the now-classical E-R random networks [3]. This includes, for instance, the "robust and yet fragile" phenomenon [9]. It has been stated that, if only randomly removing a fraction of nodes, the scale-free network will have no significant change, but if specifically removing a fraction of nodes that have many connections (big nodes), the network will collapse almost for sure. The scale-free feature in the network topology determines the dynamical behaviors of the network. The synchronizability and its robustness as well as fragility of scale-free dynamical networks have been studied in Ref. [10], and in Ref. [11] it argued that only purposefully stabilizing those big nodes will easily stabilize a scale-free dynamical network. All these dynamical phenomena result from the extreme non-homogenous nature of scale-free networks. On the other hand, the dynamics of big nodes in a network will spread via their connections and will affect and even dominate the dynamics of a great number of small nodes in the network.

The world economy is more and more like an Earth village due to its globalization process today [12]. With the liberalization of capital accounting and international trading, the globalization process makes the world a global village, and the trade plays a more and more important role as the central inter-country connections. International trade not only is the exchange of goods and services among different countries, but also is a channel for communication that describes the spreading of each country's economic dynamics. The financial crisis of the East Asia in 1997 is such an instance, where the crisis in one country propagated to the other countries in a way like disease spreading through a network [13]. The latest IT depression of Silicon Valley in USA has also delayed other developed countries' economic recovery. Hence, to gain further insight into such complex dynamical economic behaviors, one should cast the whole world economy in a connected network of international trade. In such a World Trade Web (WTW), every country is a dynamical node, and the connections between any pair of countries are their imports and exports. In Ref. [14], it argued that the topology of the WTW, far from the random-network description, has a scale-free degree distribution and some other properties of complex networks. In Ref. [14], the study was based on the recovered topological matrix, where every country is identical regardless of its size and wealth. In this letter, the WTW will be rebuilt and re-investigated. Its scale-free features with identical and non-identical nodes will be further studied, and its dynamical synchronization phenomenon will be discussed in detail.

2. Scale-free feature of the WTW

In Ref. [14], data were extracted for analysis from aggregated trade statistics tables available in the International Trade Center website, which is based on the COMTRADE database of the United Nations Statistics Division [15]. Those data contain, for each country, an import list and an export list detailing the 40 exchanged merchandises in the year 2000, including reports from primary and secondary markets. To overcome the data limitation of describing only a subset of the actual trade connections among different countries, in Ref. [14] the symmetry of the import and export connection was assumed and applied to "recover" missing information from the original matrices, that is,

$$A_{ij}^{imp} = \frac{1}{1 + \delta_{(\tilde{A}_{ij}^{imp} + \tilde{A}_{ji}^{exp}),2}} [\tilde{A}_{ij}^{imp} + \tilde{A}_{ji}^{exp}] , \tag{1}$$

where $\delta_{x,y}$ is the Kronecker delta function of variable x and y, $A_{ij}^{imp} = A_{ji}^{exp}$ is the complete recovered adjacency matrix, $\tilde{A}_{ij}^{imp}$ and $\tilde{A}_{ji}^{exp}$ are the import and export adjacency matrices, respectively, calculated from the import and export databases, whose elements $\tilde{a}_{ij}^{imp}$ or $a_{ji}^{exp} = 1$ if country i imports from or exports to country j, and they are zeros otherwise. After completing a network-building procedure, it was obtained in Ref. [14] a directed network with 179 nodes representing 179 countries along with 7510 directed links representing the import and export connections among different countries. The cumulative degree distribution fits the power-law form $P(k) \sim k^{-\gamma}$ with $\gamma = 1.6$.

Differing from the recovered trade adjacency matrices suggested in Ref. [14], we collected all real trade data from the statistics of the International Monetary Fund, where all trade connections with values higher than 1 million US dollars are given statistically [16]. So, in our import and export adjacent matrices, the elements a_{ij}^{imp} or a_{ji}^{exp} equals 1 if country i imports or exports merchandises more than 1 million US dollars from country j, and they equal zeros otherwise. For instance, in year 2000, the United States has exported its merchandises to 195 countries and regions and imported merchandises from 189 countries and regions, hence the node representing the United States has 195 export degree and 189 import degree. This shows that our model does not assume symmetry, which is different from the model studied in Ref. [14]. In the Directions of Trade Statistics Yearbook 2001 [16], there are 188 countries and regions' statistical data, with 12 413 export and 12 669 import connections in year 2000. Fig. 2 is the log–log plot of the cumulative import and export connectivity distribution of our newly built WTW. It can be observed that the import and export degree distributions both fit the power-law $P(k) \sim k^{-\gamma}$ with exponents $\gamma^{exp} = 1$–3.6 and $\gamma^{imp} = 1.6$–2.9, respectively. Some countries have their import and export degrees listed in Table 1.

In Figs. 1 and 2, all countries are regarded as identical nodes regardless their sizes and wealth, with different degrees. As shown in Table 1, the United States and the United Kingdom are the two biggest nodes in the identical WTW. Generally, a country imports resources and merchandises to improve its economy development and people's living quality, and exports resources and merchandises to balance its financial account and to make money. So, the export and import sums of countries represent the world resources and wealth flows and distributions among different countries. Fig. 3 is such a log–log export and import sums of the 188 countries and regions given in Ref. [16], and the corresponding export and import sums of every country are the values of dots world total in year 2000 given in Ref. [16]. It can be observed that the cumulative

Table 1
The export and import degrees of some nodes (countries) in the WTW of Fig. 2

Country	Export degree	Import degree
USA	195	189
UK	195	179
China: Mainland	183	139
Australia	153	124
Hungary	103	99
Israel	108	93
Luxembourg	97	60
Austria	160	118
Germany	191	183
Japan	186	176
China: Hong Kong	162	130
Canada	166	153
Iceland	44	65
Mexico	76	78
Mongolia	14	37
Tonga	4	9

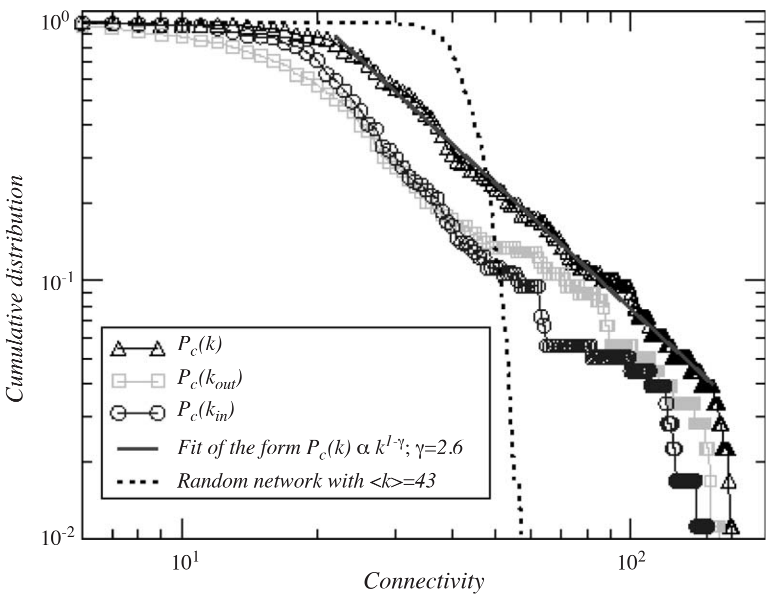

Fig. 1. Cumulative degree distribution of the WTW with 179 nodes and 7510 directed links, where the solid line is the power-law form $P(k) \sim k^{-\gamma}$ with $\gamma = 1.6 \pm 0.1$ (after Ref. [14]).

distribution of the trade sums fits the power-law $P(k) \sim k^{-\gamma}$ with exponent $\gamma = 0.5$–1.8. That means the world wealth and resources are distributed via trade connections extremely non-homogenously among countries.

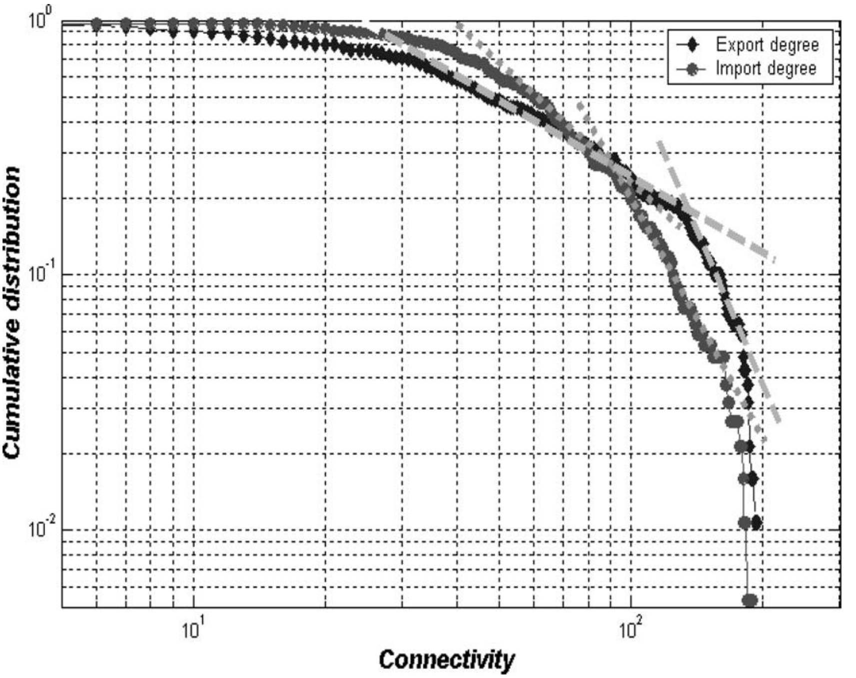

Fig. 2. Cumulative import and export degree distributions of the WTW with 188 nodes and 12 413 export links and 12 669 import links. The dashed line is the power-law form $P(k) \sim k^{-\gamma^{exp}}$ with $\gamma^{exp} = 1$–3.6, the dotted line is the power-law form $P(k) \sim k^{-\gamma^{imp}}$ with $\gamma^{imp} = 1.6$–2.9.

The heterogeneity of trade sums distributions as seen from Fig. 3 means that it is ivory towered regardless of the sizes and wealth of nodes in the WTW. For a better description, we will further study the WTW in a weighted degree sense. The import and export degrees of every node (country) in the WTW will be multiplied a weight value w_i^{imp} and w_i^{exp}, respectively, and each country has its weights probably different from that of the other countries. The weights w_i^{imp} and w_i^{exp} of country i are defined as

$$w_i^{imp} = \frac{imp(i)}{\sum_j imp(j)} \times 100, \qquad w_i^{exp} = \frac{exp(i)}{\sum_j exp(j)} \times 100 \,, \tag{2}$$

where $imp(i)$ and $exp(i)$ are the import and export sums of country i, respectively. Hence, the weight w_i represents how much the trade of country i affects the world, and the weighted degree reflects how much effect of one country on how many other countries of the world. Though UK and USA both have 195 export degrees, their export sums are far different, and the latter is nearly 4 times of the former. Hence, UK and USA will have different weighted degrees, and they have different effects on the economic behaviors of other countries. Fig. 4 is the log–log plot of the cumulative distribution of the weighted degree of 188 countries and regions given in Ref. [16]. It can be observed that the weighted degree distribution fits the power-law form

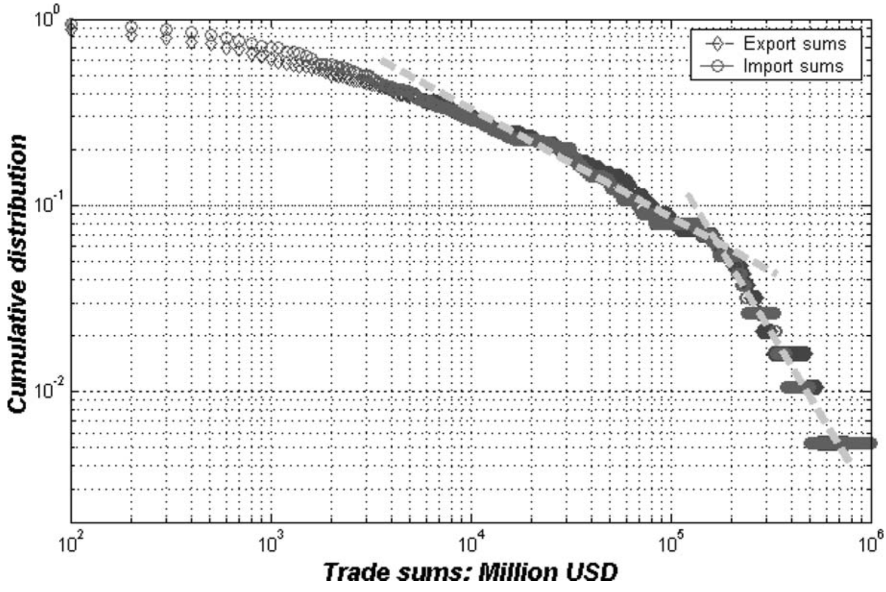

Fig. 3. Cumulative export and import sums distributions of the WTW with 188 nodes in Fig. 2. The dashed line is the power-law form $P(k) \sim k^{-\gamma}$ with $\gamma = 0.5$–1.8.

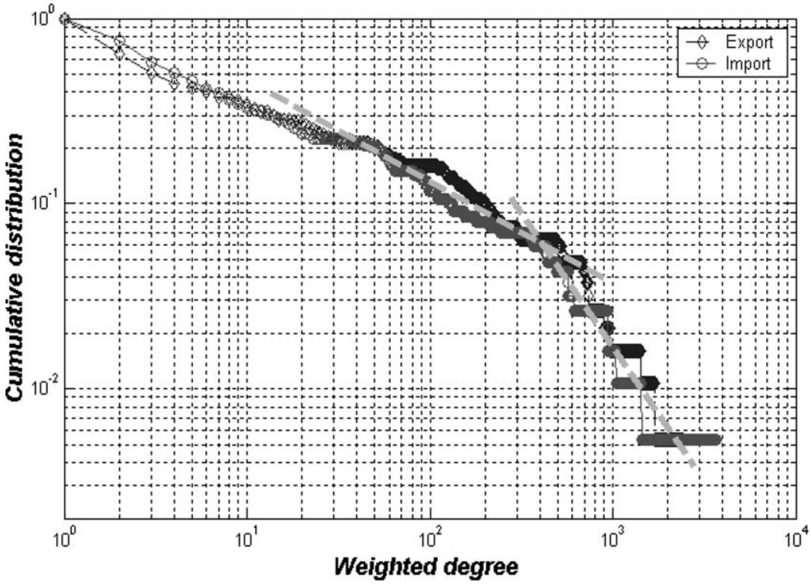

Fig. 4. Cumulative import and export weighted degree distributions of the WTW with 188 nodes and 12 413 export links and 12 669 import links. The dashed line is the power-law form $P(k) \sim k^{-\gamma}$ with $\gamma = 0.6$–1.6.

Table 2
The export degrees and export weighted degrees of some nodes (countries)

Country	Degree	Weighted degree
USA	195	3663
UK	195	938
China: Mainland	183	490
Australia	153	131
Hungary	103	50
Israel	108	53
Luxembourg	97	11
Austria	160	133
Germany	191	1433
Japan	186	1039
China: Hong Kong	162	434
Canada	166	572
Iceland	44	3
Mexico	76	213
Mongolia	14	0
Tonga	4	0

Remark: All weighted degrees have been kept to the precision of 10^0.

$P(k) \sim k^{-\gamma}$ with exponent $\gamma = 0.6$–1.6. Table 2 shows the export degrees and the export weighted degrees of those countries listed in Table 1. It can be observed that in the weighted WTW, the United States is the biggest node, far bigger than others.

3. Economic cycle synchronization on the WTW

As argued before, the complexity of network topology usually dominates the dynamical behaviors of a network, and the stability of a few ‘big’ nodes determine the synchronizability and stability of a scale-free dynamical network [10,11]. In such an economic dynamical WTW, its scale-free features result in a few big nodes (countries), which can affect other ‘small’ nodes’ economy through the close trade connections. The United States is the unique ‘biggest’ node in the WTW. Of particular interest is to what extent the economy of the United States affects the economic development in other relatively ‘smaller’ countries. Here, we focus the economic dynamics on the WTW as the economic cycle in different countries, and we want to find out whether there is synchronization of economic cycles existing between the United States and other countries.

The economy development in a country is too complex and may be affected by many unpredictable factors, such as the significant change of economic or political regimes occurred in a large country like USSR and those eastern European countries, the shock from those speculation money such as the Quantum Fund of George Soros, the continuation of a country’s economic policy, the change of exchange rate policy, wars, etc. Hence, in studying the synchronization phenomenon of economic cycles, to decrease the perturbations on economy development from unreasonable 'noise' to the minimum extent, we should probe those countries where stable and peaceful political situations and mature market economic systems have been very well maintained. A suitable choice is the 23 developed countries, i.e., the United States, the United Kingdom, Germany, Japan, France, Canada, Australia, Austria, Belgium, Norway, Italy, Finland, Denmark, Greece, Ireland, Iceland, Netherlands, Portugal, Spain, Sweden, Switzerland, New Zealand and Luxemburg.

The economic cycle synchronization is characterized by the correlation between the cyclical components of outputs of two arbitrarily chosen countries, i and j [20,21]

$$corr(y_i^c, y_j^c) = \frac{cov(y_i^c, y_j^c)}{\sqrt{var(y_i^c)var(y_j^c)}}, \quad i,j = 1,2,\ldots,n \tag{3}$$

where y_i^c is the cyclical component of output of country i, and here can be specialized as the real gross domestic product (GDP). A positive correlation means that synchronization exists in the economic cycles between countries i and j, and higher correlations imply a higher degree of synchronization of economic cycles.

We collected the real GDP of the 23 developed countries during the years of 1975–2000 from the databases [18,19]. Because there are no real GDP data of Switzerland during 1975–1984, we only calculated the correlations between USA and the other 21 developed countries with the 1975–2000 real GDP data (the real GDP data in 1975–1984 are average values given in Ref. [18]), and the corresponding real GDP cycles' correlations are shown in Fig. 5. It can be observed that in 1975–2000, totally 18 developed countries did have significant economic cycle synchronization with the United States, and five countries (the United Kingdom, Australia, Canada, Finland, Sweden) show much stronger synchronization of economic cycles. The exceptional are only three countries: Japan, Germany and Austria. The reason is unclear from the available data, but some discussions will be given in the last section of this letter. Therefore, there indeed exists synchronization of economic cycles between the United States and the other countries, which implies that economic dynamics are spreading throughout the weighted WTW.

4. Conclusions and discussions

In this letter, we have investigated some scale-free features of the WTW, where the United States is the 'biggest' node in the weighted degree sense. To study the economic synchronization on the WTW, real GDP data in the years of 1975–2000 for 21 developed countries were analyzed in terms of their correlations with the United States, and the outcome is that 18 developed countries indeed show significant synchronization of economic cycles with the United States. This verifies that the dynamics are spreading throughout the World Trade Web, which has scale-free features.

As argued in Ref. [22], the growing and preferential attachment mechanisms are two ingredients of scale-free features in complex networks. However, the nodes (countries) are kept constant in the WTW. It was shown in Ref. [14] that for countries with trade connections with less than 20 other countries, the preferential attachment mechanism

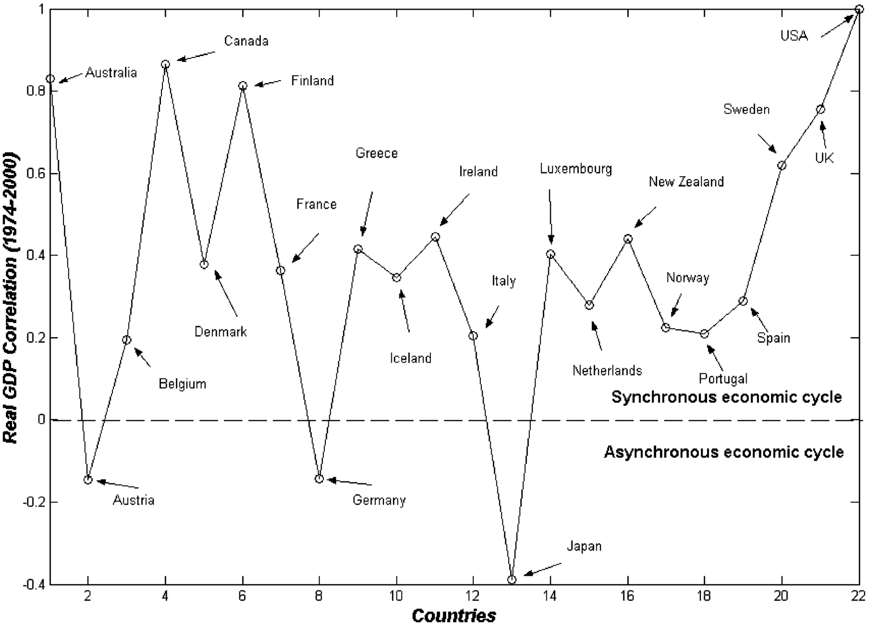

Fig. 5. Twenty-two developed countries' economic cycles synchronization phenomena. The positive real GDP correlation means synchronous economic cycles of those indicated countries with the United States, and the negative correlation means asynchronous economic cycles of the indicated countries with the United States.

does not work. It was also argued in Ref. [23] that this is a local-world effect on scale-free networks, and the local-world scale determines the extent of heterogeneity of a scale-free network. As in the real-life economy world, some regional economic cooperative organizations such as EU, ASEAN, and NAFTA have been founded, and many countries have accelerated the economy cooperation in their regions. An example in point is that, in 2002, more than $\frac{1}{3}$ of the USA imports/exports were exchanged from/to Canada and Mexico [17]. Hence, it can be regarded as that the preferential attachment mechanism works in local-world economy, and the viewpoint of local-world effect on the WTW is convincible.

It is also very interesting to see that there are three developed countries (Japan, Germany and Austria) showing economic asynchronous phenomena with the United States in the years of 1975–2000. In particular, we have found that Austria shows a very strong synchronization of economic cycle with Germany due to their positive real GDP correlation of 0.8308. Something happened in Japan and Germany during that period may give us some ideas about the asynchronous phenomena with the United States. The appreciation of Japanese currency Yen by the Plaza Accord in 1985 pierced the bubbles of the Japanese economy, and it directly resulted in the Japanese economy depression since 1990. After Germany was unified in 1992, great efforts were made for helping the eastern Germany to catch up in economy. Some special economic strategies including loosening fiscal and monetary policies have been applied, which however broke the normal economic developing route. These issues may explain why these two countries have asynchronous economic cycles with the United States. However, owing to the complexity of the WTW, its dynamical behaviors are still far from being clear today.

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