EN.560.653.01.FA21 An Introduction to Network Modeling

The World Trade Network Analysis Project Final Report

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Content

1. Introduction

Bilateral trade or clearing trade is trade exclusively between two states, particularly, barter trade based on bilateral deals between governments, and without using the hard currency for payment. Bilateral trade agreements often aim to keep trade deficits at a minimum by keeping a clearing account where deficits would accumulate. Traditional trade studies look at things like trade costs, a country's comparative advantage, the impact of exchange rates on trade patterns, and bilateral trade agreements. When seen as a complicated network, however, trade figures can provide valuable insight. Densely connected nodes, together with their degree of connectedness, can be used to identify influential nodes in a network, which can then be used to better understand the trade network's structure.

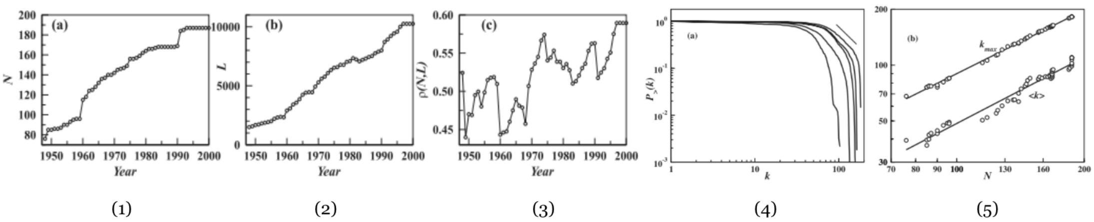
There are 161 countries or regions officially counted by the UN in the world producing bilateral trade. The world trade network (WTN) defined as $\mathcal{T} = \{\mathcal{N},\ \mathcal{A},\ \mathcal{W},\ \mathcal{V}\}$, which refers to the trade network formed by the mutual bilateral trade between the above-mentioned countries. The first part of the network is the graph $\mathcal{G}(\mathcal{N},\ \mathcal{A})$, where nodes $\mathcal{N} = \{1, 2, \cdots 161\}$ is the set of the countries and regions and links $\mathcal{A} = \{1, 2, \cdots m\}$ is the set of trade flows between pairs of nodes. $\mathcal{G}$ is a directed graph as the trade flows are directed from the export country *e* to the import country *i*, where $\mathcal{A}_{ei} \in \{0,\ 1\}$. The second part of the network is the network characteristics $\mathcal{C}(\mathcal{W},\ \mathcal{V})$ where $\mathcal{W}$ is the line value function and $\mathcal{V}$ is the vertex value function (De Benedictis & Tajoli, 2011). The volume of trade between the two countries is regarded as a measure of the degree of mutual economic dependence. The positive element w_{ei} in $\mathcal{W}$ serves as the binary weight of $\mathcal{G}$, transforming the simple directed graph into a weighted network, where w_{ei} represents the degree of the connection between country *e* and country *i*. $\mathcal{V}$ includes the unique value of each country. In this study, $\mathcal{V}$ mainly includes geographic location, global ecological footprint, and human development index et. al.

By analyzing the network of bilateral trade in different years, the development of the world and the closeness of the connection and trade can be revealed. From another perspective, although it may not be as complex as a multi-node network, the relationship between nodes in WTN is very complicated. Therefore, even small changes in graph topology may have a huge impact on the overall structure of the network. Most research on WTN was completed at the beginning of the 21st century. In order to study the complex interrelationships and dynamic evolution between various countries and trade, it is necessary to fully understand the potential structural characteristics of WTN. This project aims to reveal some of the key characteristics that characterize WTN, identify dominant nodes and the way they manage the network, and study the carbon trading issues and wealth gap problems derived from WTN.

2. Literature review

Many researchers around the world have conducted extensive and profound analysis of WTN. As far as the trade network itself is concerned, Bhattacharya, Mukherjee and Manna (2007) studied the changes in WTN from 1948 to 2000, and the results are shown in the figure below.

Figure 1. Summary of WTN 1948-2000



Note:

1) Variations of the total number of nodes *N*
2) Variations the total number of links *L*
3) Variations of the link density *ρ(N,L)* of the annual WTN over a period of 53 years from 1948 to 2000.
4) Cumulative degree distributions *P>(k)* vs. k averaged over the ten year periods during 1951–60, 1961–70, 1971–80, 1981–90 and 1991–2000 (from left to right). No power law variation is observed for the 1951–60 plot. For the next decades however power laws over small regions are observed whose slopes gradually decrease to 1.74 for the 1991–2000 plot.

5) Average nodal degree k and the largest degree kmax with the size N of the International Trade Network.

The result shows that over time, the number of nodes in WTN remains stable, but the number of connections and link density dynamically increase. At the same time, not only have more countries joined the WTN, but in general, individual countries have established trade relations with more and more other countries, which reflects the liberalization of the global economy. Garlaschelli and Loffredo (2005) studied the complete evolution, directed description, and time dependence of topological parameters of WTN. As seen in their results, the wealth dynamics model on complex networks demonstrates how topology impacts the form of wealth distribution. De Benedictis and Tajoli (2011) used gravity model regression and analyzed the density, proximity, betweenness, degree distribution of WTN. They pointed out the role of trade policy in shaping the trade network. The result emphasizes the structural difference between the extensive trade margin and the intensive trade margin and the relationship between them and the entire trade network. Ward, Ahlquist and Rozenas (2013) combined the gravity model specification with the "latent space" network, developed a dynamic hybrid model for real-valued directed graphs and demonstrated the usability of the model by tracking the trade tendency between the United States and China.

WTN is also accompanied by many extension problems. Ermann and Shepelyansky (2011) constructed the Google matrix of the WTN and used PageRank and CheiRank algorithms to build node rankings. The result confirmed the existence of two solid domains of rich countries and poor countries, and they remained stable over time, but most countries showed that they were in a dynamic stage with strong level fluctuations. Aller, Ductor and Herrerias (2015) revealed the relevance of trade networks to the environmental impact. Trade volume also affects the environmental quality and the status of each country in the world trade network. This effect indirectly improves the environmental quality of low-income countries, but has a negative impact on the environment of high-income economies. At the same time, the results show the importance of major policies. In addition, Ottaviano (2002) in his network analysis proposed that the core country is the country with the main production activities in the field of new economic geography, and it also involves countries with a large number of trade connections.

Giorgio Fagiolo (2008) in his results prove that very reliable network analysis allows people to reach very different conclusions compared to the binary network framework. Also, his findings seem to be very reliable for alternative, economically dominant solutions that WTN is a strong state network. The core of the network has a peripheral relationship, so there may be a core-peripheral structure. In addition, countries with poorer connections tend to trade with countries with better connections, while the latter involves relatively highly interconnected trade triads. In addition, high-income countries tend to form closer trade ties and tend to gather more. Therefore, factions are established along the lines of connectivity and income levels, and can be seen as a sign of the continued relevance of local relations. However, the inconsistent nature of WTN proves the increasing importance of global links: poorly connected nodes tend to connect to central nodes and use them as hubs to access the rest of the network. Finally, all structural characteristics of WTN have shown remarkable stability over the years from 1990s to 2000s. The stability of the WTN structure shows that the integration of the international commodity market has not increased significantly, or from a different perspective, although the degree of economic integration has increased, the core of the WTN has hardly been affected.

3. Data Sources and Methodology

3.1 Overview

The United Nations Comtrade database and BACI-CEPII data set are well-known in the trade field, have high reliability, and are widely cited by researchers. The WTN studied in this article is concentrated in 161 economic entities defined by the United Nations, so this article uses the United Nations Comtrade database. The United Nations Comtrade database is the world's largest online repository, and it has been utilized by a variety of organizations to conduct trade analysis and research on the emergence and growth of trade. This has been used to investigate the export of food-safety-related commodities, intra-regional trade dynamics, and the dispersion of trade in intermediate and final products. The Global Ecological Footprint (GEF) quantifies the ecological assets required by a given population to produce the natural resources it consumes (such as plant-based food and fiber products, timber and other forest products, and space for urban infrastructure et. al.) and to absorb its waste, particularly carbon emissions (Wackernagel & Rees, 1998). Cropland, grazing land, fishing grounds, built-up (or urban) land, forest acreage, and carbon demand on land are all tracked by the footprint. The Human Development Index (HDI) is a summary assessment of average accomplishment in major characteristics of human development, such as living a long and healthy life, being knowledgeable, and having a good standard of living. The HDI is the geometric mean of the normalized indices for each dimension (United Nations Development Programme, n.d.).

3.2 Data description

3.2.1 United Nations Comtrade database

UN Comtrade International Trade Statistics Database is published by Statistics Division of UN Department of Economic and Social Affairs. It generates analytical merchandise trade tables for countries (areas) and regions, incorporating trade values and indexes.

Website: https://comtrade.un.org/

Dataset: https://comtrade.un.org/Data/

3.2.2 Global Ecological Footprint

Mathis Wackernagel and William Rees of the University of British Columbia invented the ecological footprint measurement. The Global Footprint Network offered ecological footprint statistics.

Website: https://www.footprintnetwork.org/

Dataset:

https://data.footprintnetwork.org/?_ga=2.147989111.1927544151.1638761475-844381179.1638322309#/compareCountries?type=EFCtot&cn=all&yr=2015

3.2.3 Human Development Index (HDI)

The United Nations Development Program compiles and publishes the annual HDI, which uses various indicators to quantify the performance of countries in various dimensions.

Website: http://hdr.undp.org/en/content/human-development-index-hdi

Dataset: http://hdr.undp.org/sites/default/files/2020_statistical_annex_all.xlsx

3.3 Methodology

3.3.1 Node degree

In a directed Network, the degree is the sum of indegree and outdegree. The indegree of a node, k_i^{in} is the number of incoming arcs, and the outdegree of a node, k_i^{out} is the number of outcoming arcs. In WTN, the degree is also weighted, so we must analyze the weighted degree.

3.3.2 Density

The ratio of the number of connections that may exist between all nodes in the density map and the maximum number of connections that may exist between all nodes. It can help us understand the degree of connectivity of a network compared to its possible connectivity, and compare the differences between two networks with the same number of nodes and the same relationship type.

3.3.3 Centrality

It uses graph theory to calculate the importance of any given node in the network. There are two types of centrality used:

- Degree centrality

In the unweighted network, degree centrality is defined as $C_D = \sum_{j\neq i}^{N} \mathcal{A}_{ij}$. The measure of degree centrality depends on the number of existing nodes in the network, so it is difficult to compare networks with different node sizes. However, the number of countries included in the WTN analysis is constant, so unified naturalization is not required. In a directed network, there are two measures of degree centrality: in-degree centrality C_D^{in} measures the number of arcs pointing to the Node i, and out-degree centrality C_D^{out} measures the number of arcs pointing away from the Node i, which can be expressed as:

$$C_D^{in} = \sum_{j\neq i}^{N} \mathcal{A}_{ji}, C_D^{out} = \sum_{j\neq i}^{N} \mathcal{A}_{ij}$$

- Closeness Centrality

It is a measure of the distance (in terms of topological distance) between a node and all other nodes. Normalized Closeness Centrality can be expressed as: $C_C^N = \frac{(N-1)}{\sum_{j\neq i}^{N} \mathcal{D}_{ij}}$

Where $\mathcal{D}_{ij}$ is the number of steps in the shortest path between i and j. In the directed network, the out-closeness centrality $C_{C\ out}^N$ indicates the sum of the geodesic distances of country i, normalized by the maximum number of possible export partners. The in-closeness centrality $C_{C\ in}^N$ indicates a similar measure for import partners. They can be expressed as:

$$C_{C\ out}^N = \frac{(N-1)}{\sum_{j\neq i}^{N} \mathcal{D}_{ij}}, C_{C\ in}^N = \frac{(N-1)}{\sum_{j\neq i}^{N} \mathcal{D}_{ji}}$$

According to De Benedictis et. al. (2014), in a directed weighted network, the weighted path in closeness centrality is a mixture of two components: the length of the path (that is, the minimum number of steps between i and j) and the strength of single step of the path (that is, bilateral trade flows). If the components are determined using multiplication, the second component will overstate the weighted length of the path between the two nations, decreasing the relevant country's centrality. This project follows the procedure proposed by Opsahl (2009) and Newman (2010).

The Dijkstra's algorithm (1959) is applied to a modification of the original trade weighted matrix. In this situation, the components in the line value function are not the bilateral trade flows $\mathcal{W}_{ij}$, but rather the share of, and average bilateral trade volume in global trade $\omega_{ij} = N\frac{w_{ij}}{\sum_i \sum_j w_{ij}}$. Under such circumstances, the weighted geodesic distance determined by the Dijkstra algorithm by:

$$\ell_{ij} = min\left(\frac{1}{\omega_{iz_1}} + \frac{1}{\omega_{iz_2}} + \cdots + \frac{1}{\omega_{z_{n-3}j}} + \frac{1}{\omega_{z_{n-2}j}}\right)$$

where the *z*s are the intermediate steps necessary to reach node *j* from node *i*. Therefore the normalized weighted closeness centrality for directed networks is:

$$C_C^{NW}{}_{out} = \frac{(N-1)}{\sum_{j\neq i}^{N} \ell_{ij}}, C_C^{NW}{}_{in} = \frac{(N-1)}{\sum_{j\neq i}^{N} \ell_{ji}}$$

3.3.4 Modularity

Modularity measures the structure of networks which measures the strength of the division of a network into different modules. In a directed weighted network, the calculation method of Modularity Q is:

$$Q = \frac{1}{2m}\sum_{ij}\left[w_{ij} - \frac{k_i k_j}{2m}\right]\delta(c_i, c_j)$$

where m stands for the number of edges of $\mathcal{G}$, w_{ij} represents the weight of the edge between *i* and *j* (set to 0 if such an edge does not exist), d_i is the degree of vertex *i* (i.e. the number of neighbors of *i*), c_i is the community to which vertex *i* belongs and the *δ*-function *δ*(*u, v*) is defined as 1 if $u = v$, and 0 otherwise.

4. Network property

Five years between 2000 and 2018 were selected to build trading networks. The nature of the network is shown in the table below

Table 1. Nature of Trade Networks

Year	Nodes ($\mathcal{N}$)	Total Links($\mathcal{A}$)	Total Degree	Avg Degree	Avg Shortest Path
2000	161	16335	32670	202.92	1.13
2005	161	17201	34402	213.68	1.08
2010	161	18579	37158	230.80	1.07
2015	161	18061	36122	224.36	0.96
2018	161	14710	29420	182.73	0.87

In 2000, the number of nodes in the world trade network was 161, which meant that 161 countries or regions participated in bilateral trade; the total number of links was 16335, which indicated that these 161 countries had a total of 16335 bilateral trade channels; the total number of degrees was 32670, including in-degree and out-degree, it is twice the number of edges; the average degree is 202.92, indicating that each country has an average of about 203 import and export trade channels; the average shortest path is 1.13, indicates that in order to get to any 1 country or region from any others, the average number of nodes to be traversed is 1.13.

In 2005, there are 161 countries having a total of 17201 bilateral trade channels; the total number of degrees was 34402, including in-degree and out-degree; the average degree is 213.68, indicating that each country has an average of about 214 import and export trade channels; the average shortest path is 1.08, indicates that in order to get to any 1 country or region from any others, the average number of nodes to be traversed is 1.08.

In 2010, there are 161 countries having a total of 18579 bilateral trade channels; the total number of degrees was 37158, including in-degree and out-degree; the average degree is 230.8, indicating that each country has an average of about 231 import and export trade channels; the average shortest path is 1.07, indicates that in order to get to any 1 country or region from any others, the average number of nodes to be traversed is 1.07.

In 2015, there are 161 countries having a total of 18061 bilateral trade channels; the total number of degrees was 36122, including in-degree and out-degree; the average degree is 224.36, indicating that each country has an average of about 224 import and export trade channels; the average shortest path is 0.96, indicates that in order to get to any 1 country or region from any others, the average number of nodes to be traversed is 0.96.

In 2018, there are 161 countries having a total of 14710 bilateral trade channels; the total number of degrees was 29420, including in-degree and out-degree; the average degree is 182.73, indicating that each country has an average of about 183 import and export trade channels; the average shortest path is 0.87, indicates that in order to get to any 1 country or region from any others, the average number of nodes to be traversed is 0.87.

5. Key players and communities

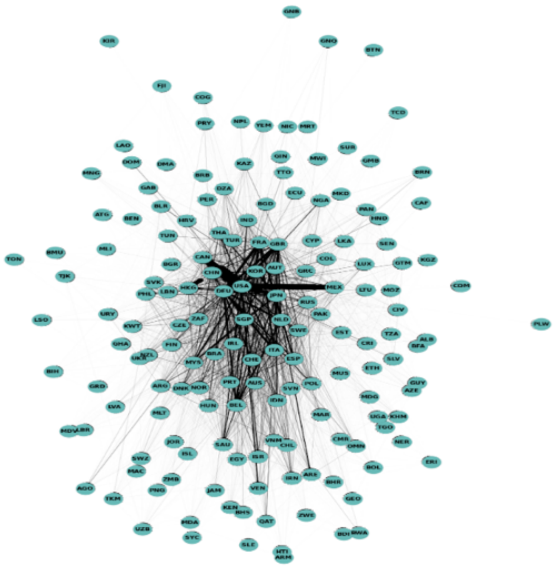
5.1 Key players

5.1.1 2000

Table 2. Top 5 Annual Bilateral Trade in Year 2000

Exporter	Importer	Trade Value
US	Canada	230000000.0
Canada	US	150000000.0
US	Japan	150000000.0
US	Mexico	140000000.0
US	China	100000000.0

Figure 2. WTN 2000



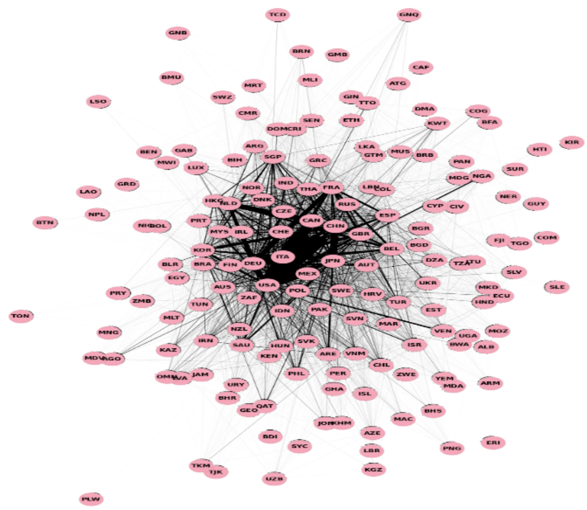
The network of year 2000 is shown above, from the table of top 5 annual bilateral trade, the United States participated in all the most valuable trades that year, and most of them were exporters. Bilateral trade between the U.S. and Canada has become the top two. In addition, Germany, the United States and the United Kingdom became the most widely connected countries that year because of their 301 bilateral trade routes.

5.1.2 2005

Table 3. Top 5 Annual Bilateral Trade in Year 2005

Exporter	Importer	Trade Value
US	Canada	290000000.0
US	China	260000000.0
Canada	US	180000000.0
US	Mexico	170000000.0
US	Japan	140000000.0

Figure 3. WTN 2005



In 2005, the most valuable trade channels still did not change their membership, but differed in order. In this year, US exports to China surpassed Canada's exports to the US and ranked second in the world. The most expensive trade lines in world trade are still dominated by the United States as an exporter. In 2005, Germany became the most widely connected countries that year because of their 300 bilateral trade routes.

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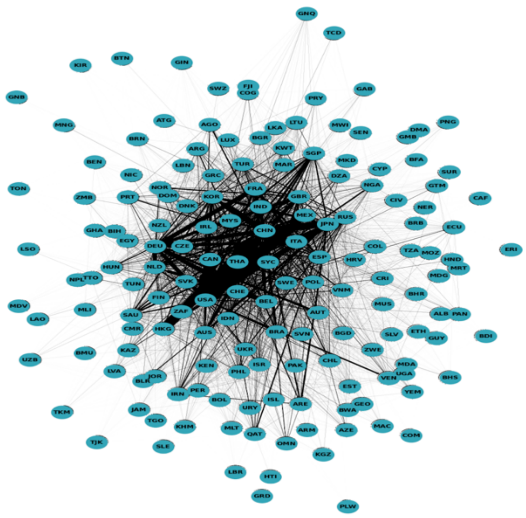
5.1.3 2010

Table 4. Top 5 Annual Bilateral Trade in Year 2010

Exporter	Importer	Trade Value
US	China	380000000.0
US	Canada	280000000.0
US	Mexico	230000000.0
Canada	US	200000000.0
Hongkong	China	200000000.0

Figure 4. WTN 2010



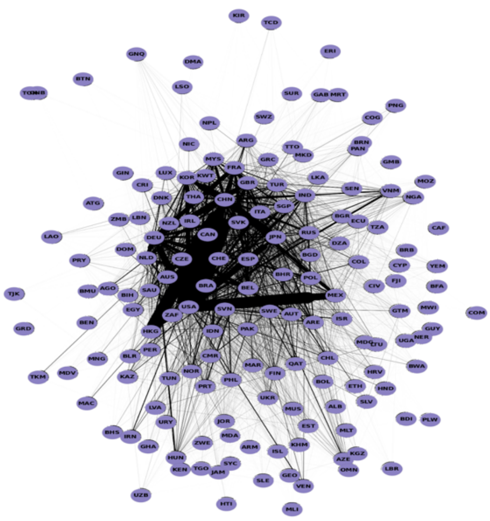
In 2010, the United States' exports to China became the world largest. It is worth mentioning that Hong Kong's exports to China during this year were the same as Canada's exports to the United States. In 2010, France and US were the most widely connected countries that year because of their 303 bilateral trade routes.

5.1.4 2015

Table 5. Top 5 Annual Bilateral Trade in Year 2015

Exporter	Importer	Trade Value
US	China	500000000.0
Mexico	US	300000000.0
Canada	US	300000000.0
China	Hongkong	260000000.0
Hongkong	China	220000000.0

Figure 5. WTN 2015



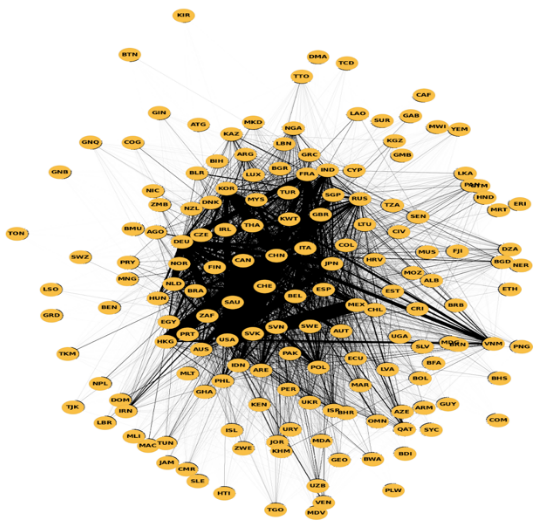
In 2015, the world's most important trade lines have undergone some changes. First, the US as an exporter's leading position in trade has changed. In addition to the fact that exports to China are still the world's largest exporter, the US has begun to act more as an importer. Participate in world trade. In 2015, China was the most widely connected countries that year because of their 293 bilateral trade routes.

5.1.5 2018

Table 6. Top 5 Annual Bilateral Trade in Year 2018

Exporter	Importer	Trade Value
China	US	479700084.683
US	Canada	340251984.929
US	Mexico	306142663.977
Hongkong	China	302198946.66
Canada	US	291962831.164

Figure 6. WTN 2018



In 2018, China's exports to the United States became the world's top for the first time. In 2018, US was the most widely connected countries that year because of their 275 bilateral trade routes.

5.1.6 Time-series analysis

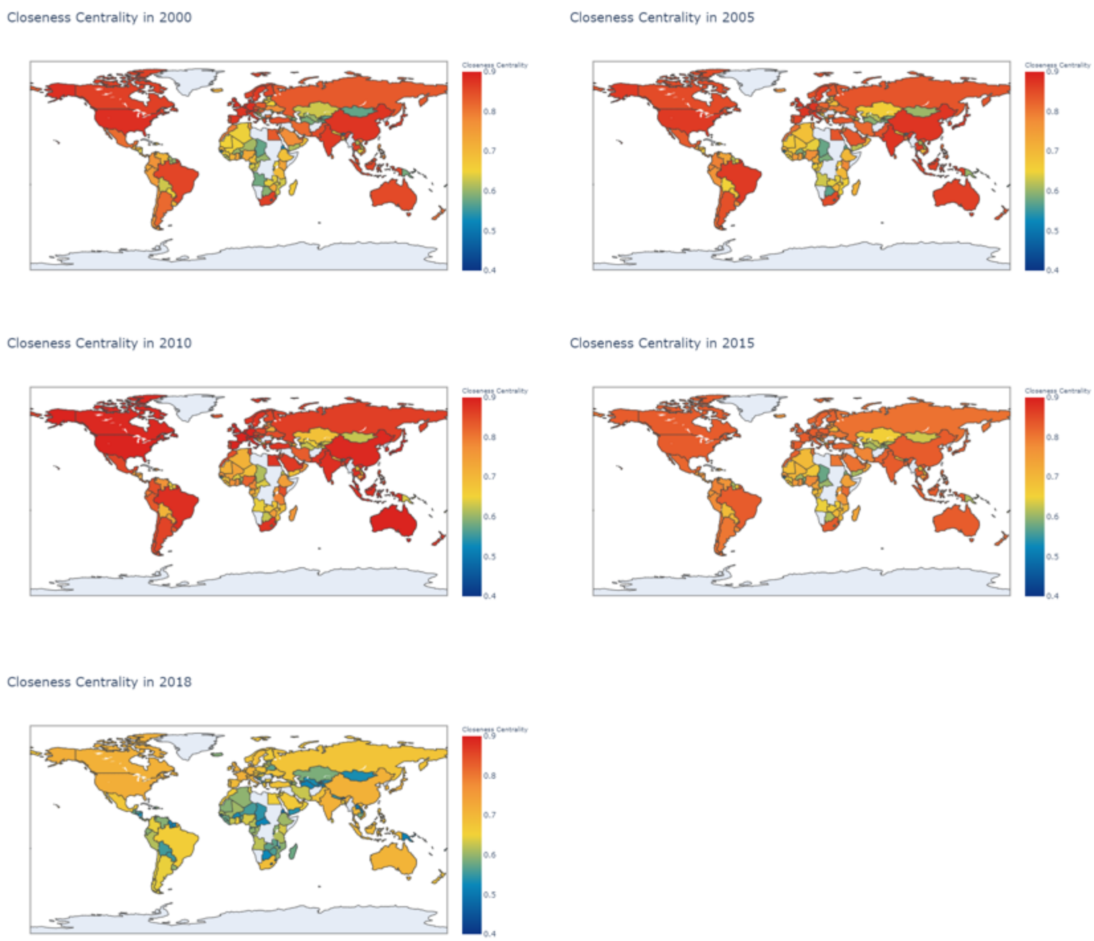
The research of trade relations and their evolution through time is critical to understanding how WTN came to be in its current position. Bhattacharya et al. (2008) did an in-depth research of the evolution of WTN from 1950 to 2000 and discovered that certain nations have weak trade linkages, and there appears to be a core structure of a wealthy country, with these countries being connected to other countries in the network more closely. The fitness network model presented by Garlaschelli and Loffredo (2005) is an essential model connected to the evolution of WTN. According to the concept, each node in the network has an intrinsic competitive component known as node fitness. Stronger linkages are attracted to nodes with better fitness at the expense of other nodes.

From the figures and tables above, as the years increase, the world's trade network has become larger and denser, but the trade network of the world's most connected countries is gradually getting smaller, mainly because with the development of society, some countries or regions have gradually assumed the role of trade transit stations, such as Hong Kong, Singapore and South Africa, along with other international regions while the trade routes of these countries and regions have declined, the trade routes of these transit stations have risen.

5.2 Centralities

The closeness centralities of all years are also calculated to reflect the changes in the world trade network over the years.

Figure 7. WTN Closeness Centrality

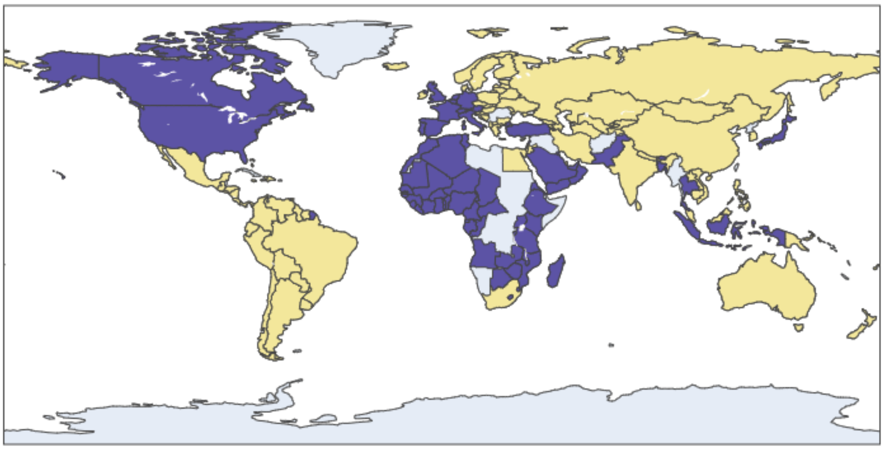


The closeness centrality of countries participating in trade were calculated and the heat map is shown above. With the development of the world, the centrality of different countries' participation in trade has become more and more average, and the average level is decreasing. On the one hand, the unfairness in world trade is decreasing, which means that the degree of participation of different countries and regions in trade has become more balanced. On the other hand, as the total trade volume increases, trade routes are decreasing, and transit points played an important position and therefore reduced the overall centrality.

5.3 Communities

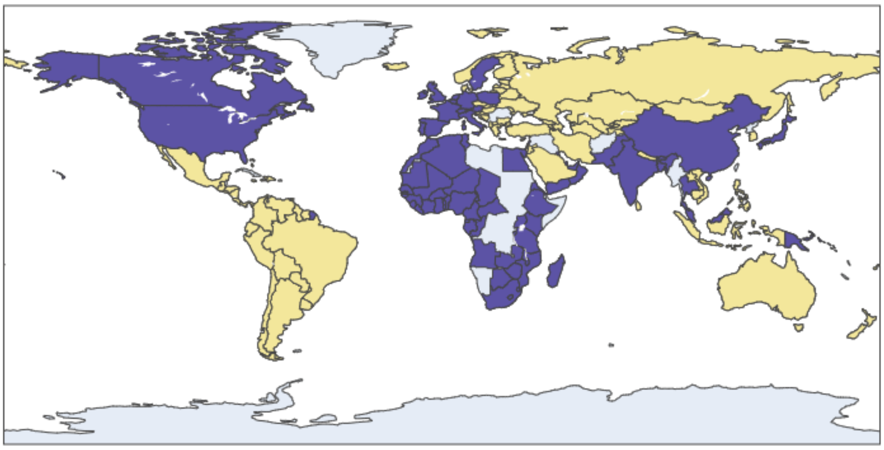
The countries and regions of the world are divided into several communities based on the modularity based greedy algorithm. The division of these communities is as follows.

Figure 8. WTN Communities 2000



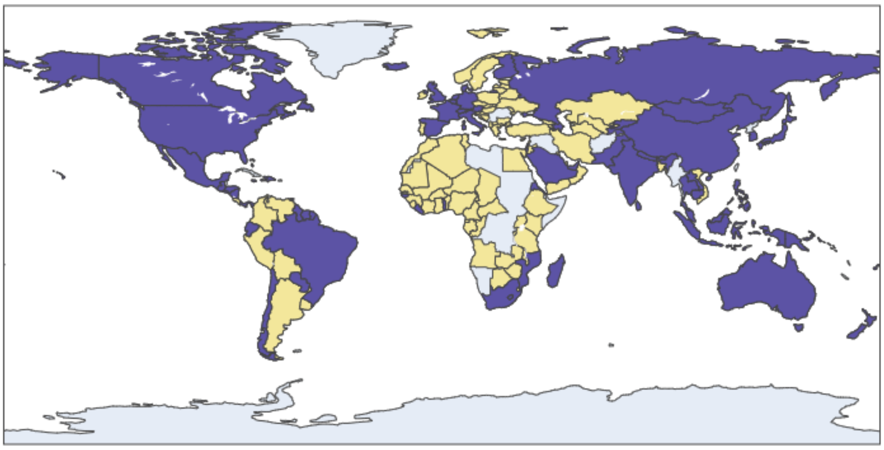
In 2000, the world was divided into two communities, namely yellow community and purple community. The white part was due to the fact that it was not counted by the United Nations to participate in bilateral trade. North America, Western Europe, and Africa are mainly divided into the same community, while Asia, South America, and Oceania are mainly in another community. Countries and regions in the same community often share a greater proportion of trade with each other.

Figure 9. WTN Communities 2005



In 2005, the main change in the world was that some countries in Asia, including India and China, and some countries in Northern Europe, such as Sweden and Ireland, joined the North American-Western European-African community. Around 2005, the United States strengthened its trade with China and India, which made the trade ties between the United States and the Asia-Pacific region closer.

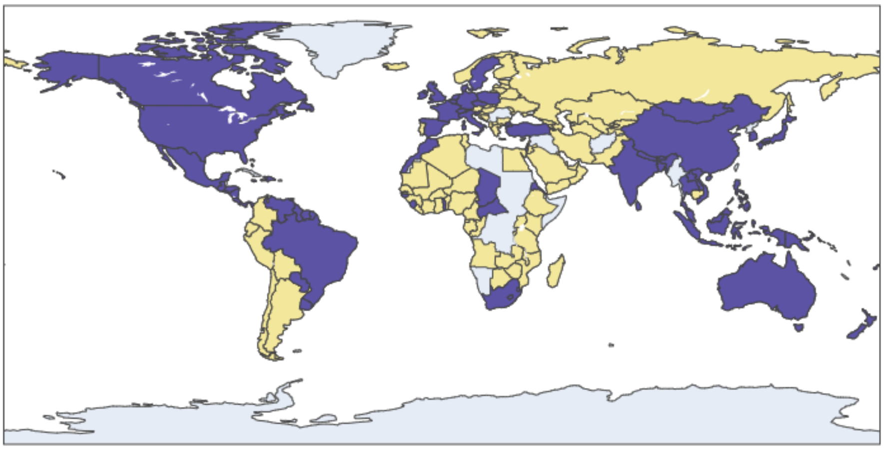
Figure 10. WTN Communities 2010



In 2010, the world trade pattern has undergone new changes, showing a trend of strong alliances. North America, Western Europe, Russia, Oceania and East Asian countries are all divided into one community. In this year, we know that Russia A large amount of energy trade has taken place with Europe, South America, and China and the United

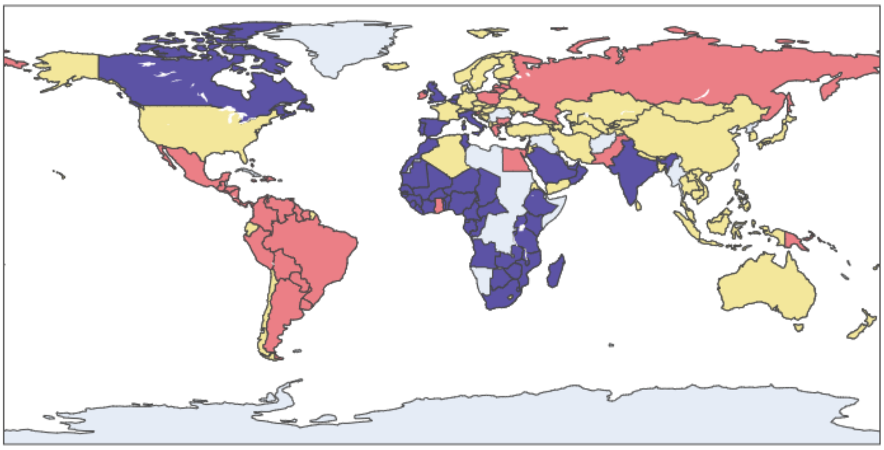
States. Around 2010, Russia strengthened energy trade with Europe (such as Germany), South America, and China, which made the ties between these countries and regions closer.

Figure 11. WTN Communities 2015



In 2015, Russia withdrew from purple community, on the one hand because of the periodicity of energy transactions, on the other hand, because Russia began to sign larger trade orders with South American countries such as Peru and Chile. In addition, the proportion of trade between the United States and these countries is relatively low relative to that of Russia, so it was in a different community from Russia in 2015.

Figure 12. WTN Communities 2018



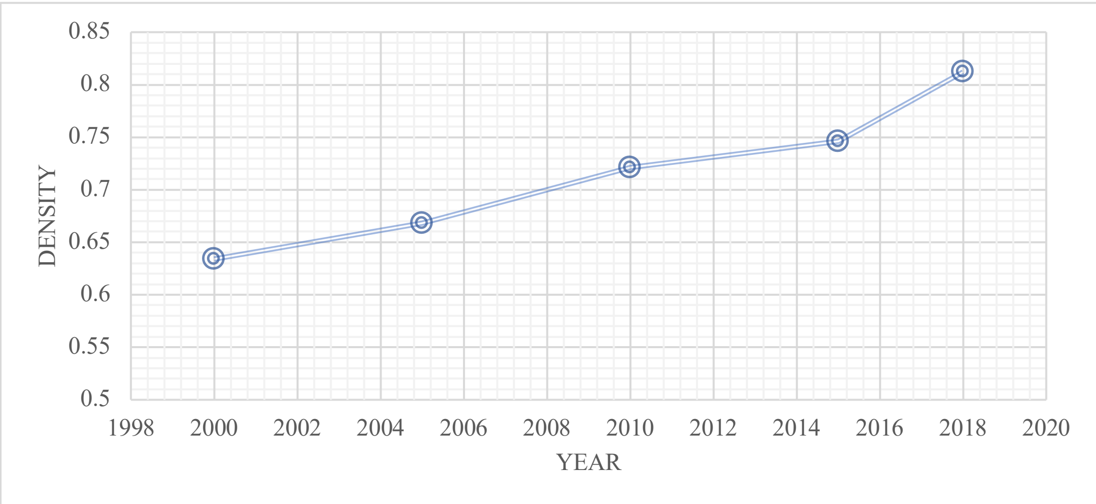
In 2018, it is surprising that the world changed from two communities to three communities. Yellow communities represented by the United States-East Asia-Oceania and some countries in Western Europe, pink communities represented by Russia, Egypt and most countries in South America, and purple communities in Canada-Africa-Saudi Arabia-India and other countries. This means that world trade is developing in the direction of multipolarity and diversification.

6. Dynamic analysis

6.1 Density change

The graph below indicates that the network's density has risen over time, indicating that nations are more connected than in prior years.

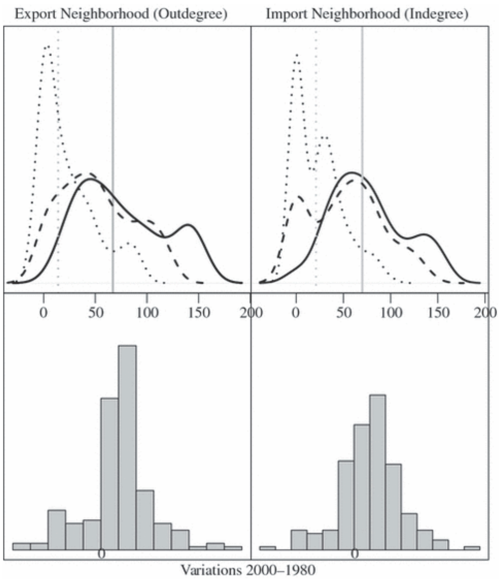
Figure 13. Density of Network



A conclusion can be drawn from the changes in the density of the network. From 2000 to 2018, the density of the world trade network is becoming more and more dense, which means that in general, the trade exchanges between countries or regions in the world are changing, which tend to be more and more concentrated and close.

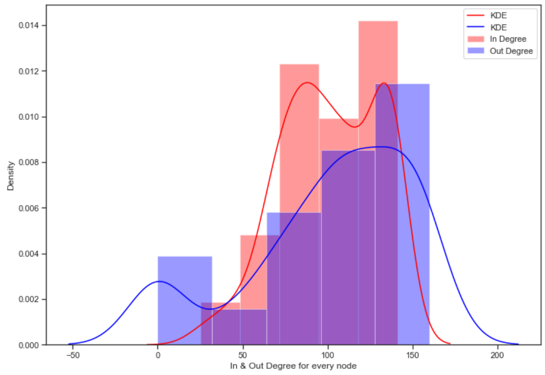
6.2 Degree change

Figure 14. Degree Change 1980-2000



Benedictis (2009) in his research analyzed the statistical relationship between the in-degree and out-degree of each country and region in the world trade network from 1980 to 2020. This project used his analysis method to produce the world trade network from 2000 to 2018. The in-out degree analysis is shown in the figure below.

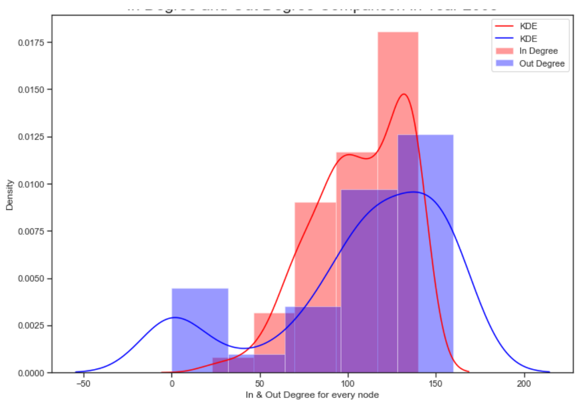
Figure 15. Degree Comparison in 2000



In 2000, the in-degree in the world trade network was more concentrated than the out-degree. The in-degree was mainly concentrated in the range of 80-120, and the degree of freedom of exit was mainly concentrated in the range of 100-150. However, there were still many countries or region that were in the range of 0-50 with their out-degree. This means that in 2000, the uneven trend of export trade was higher than that of import trade, and the scope of export trade was more concentrated than import trade. However, many countries or regions did not or participated in very little export trade. This may be due to the underdevelopment of countries that caused many products to rely on imports.

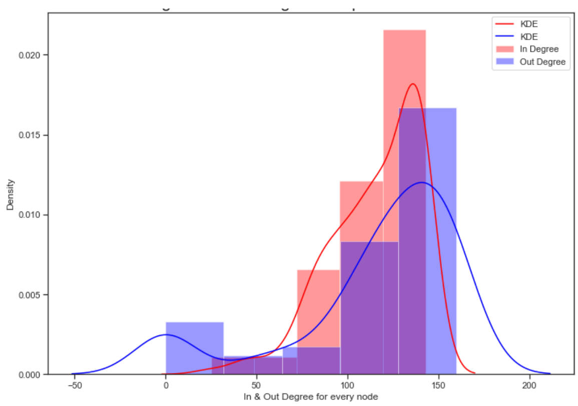
Compared to 2000, the indegree in 2005 was more concentrated in the high position. In-degree showed a very high distribution in countries or regions ranging from 120-140. At the same time, out-degree also has some centralized trends, although there are still many countries or regions is in the range of 0-25.

Figure 16. Degree Comparison in 2005



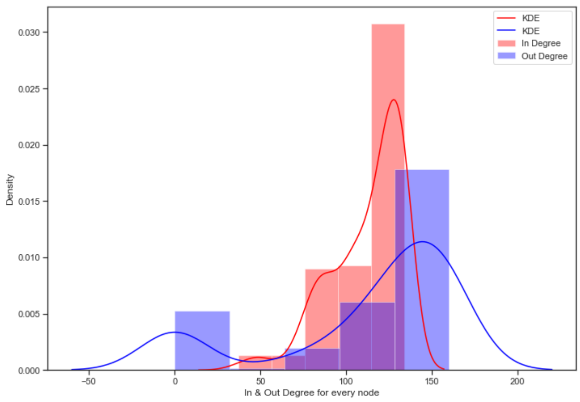
In 2010, the outdegree changed significantly. There are fewer and fewer countries or regions in the 0-50 range, but growth in the 100-150 range, which shows consistent correlation with in-degree.

Figure 17. Degree Comparison in 2010



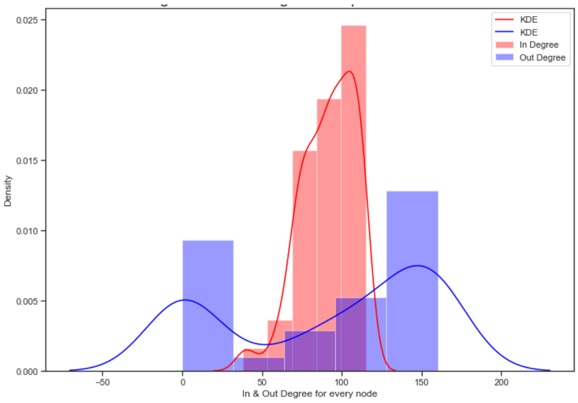
The main change in 2015 is reflected in the in-degree. The proportion of the 120-130 range has further increased and is even close to the other total. This means that the import trade of various countries has increased at a high level, and it also shows the world's import trade was shifting in the direction of diversification.

Figure 18. Degree Comparison in 2015



In 2018, the range of in-degree was further reduced, almost all concentrated in the range of 80-110, while export trade became more even and showed a trend of polarization. This is mainly because as the world changes, many countries and regions have gradually assumed the role of transfer stations. These transfer stations often have a super high out-degree to undertake exports from other countries, and once again export to other countries.

Figure 19. Degree Comparison in 2018

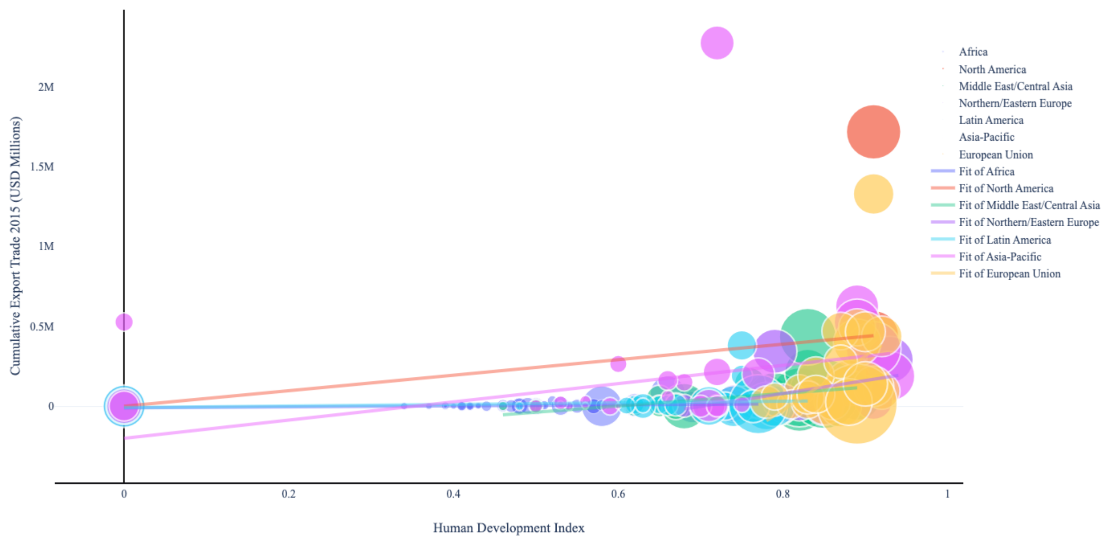


7. World trade network, environment and wealth gap

7.1 World trade network and carbon footprint

Together with GEF and HDI, the analysis is extended into three dimensions. The difference between the impact on carbon footprint, HDI and cumulative export trade 2008-2016, 2015 and 2018 was studied and there are no obvious differences. Therefore, the trade networks in 2015 and 2018 are used to do analysis to correspond with the network analysis before. The result is shown in the following Figure where the x-axis represents HDI, the y-axis represents 2015 export trade, and the size of the circle represents the country's carbon footprint.

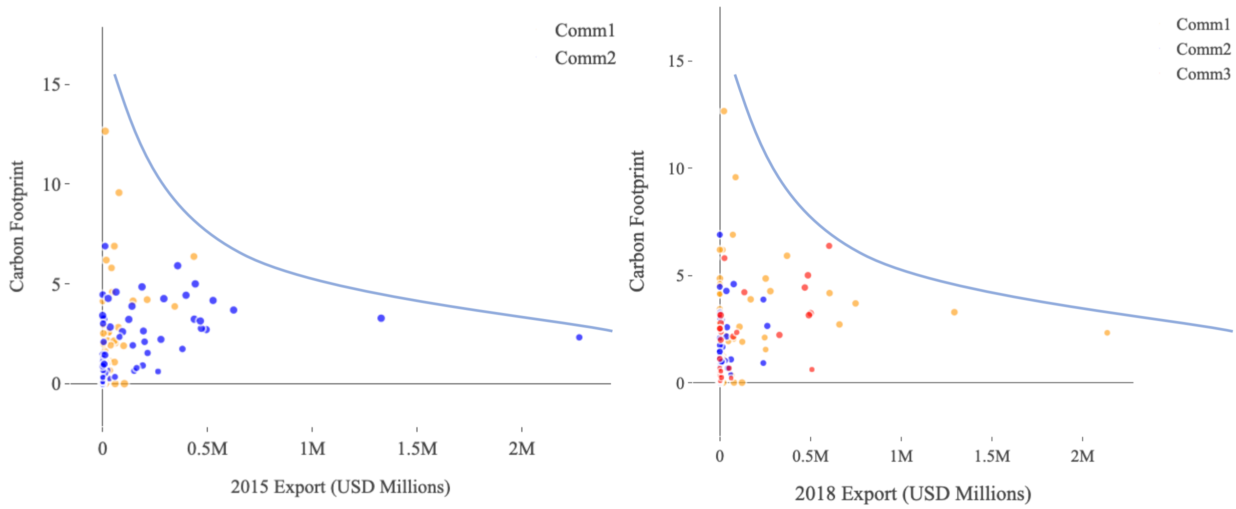
Figure 20. Impact of 2015 export trade and HDI on carbon footprint



The overall result demonstrates that Africa's bubble is very small when compared to other areas, showing that African nations are not the primary producers to carbon emissions. In comparison to Africa and other developing regions, the bubbles in North America, the Middle East/Central Asia, and the European Union are relatively large, showing that first-world nations are the primary contributors to carbon emissions. African nations have a low Human Development Index (HDI), whereas the European Union and North American nations have a high HDI (> 0.8). The size of the bubbles grows in proportion to the HDI, implying that as the standard of life and development improves, so does the carbon footprint. Most African countries have little trade (less than $5MM), whereas most industrialized countries have considerable commerce. According to the regression results of HDI and trade volume shown in the figure, countries with a higher HDI trade more, demonstrating a positive relationship between trade and HDI.

If only trade volume and carbon footprint are plotted (Figure below), it could be found that as the scale of exports decreases, the carbon footprint increases, but the variation increases with the decrease in exports at the same time, which indicates the possible heteroscedasticity relationship.

Figure 21. Impact of 2015 and 2018 export trade on carbon footprint

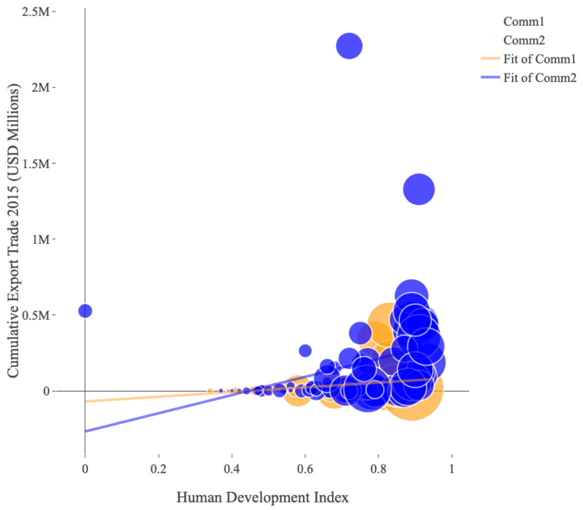


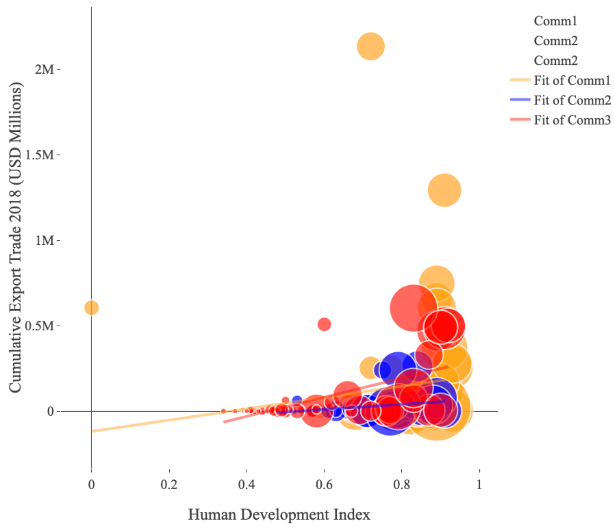
7.2 World trade network, environment and wealth gap

Based on the communities divided above, the relationship between WTN, environment and wealth gap are shown in the Figure below. It can be found that in 2015, the difference in carbon emissions and HDI distribution between the two communities was relatively small. As the world becomes more polarized, the geographical features of each group are similar to those of HDI. Carbon emissions are more concentrated in the Asia-Pacific-North America group (community 1) represented by the United States and China.

The results of linear regression analysis show that in each community, the relationship between HDI and trade remains the same, but the degree of positive correlation varies from community to community. In 2015, WTN's Community 2 (US-China) and 2018's Community 3 (Russia-South America) have a large positive correlation. This shows the large export trade gap among the members of the reform community. But in general, from 2015 to 2018, the degree of positive correlation between communities is becoming more consistent, which shows that in addition to the consistency of geographic location and HDI, the intra-community trade structure of each community may also be converging.

Figure 22. Impact of HDI on 2015 and 2018 export trade





It can also discover that when a country's HDI approaches 0.6, the country's carbon footprint appears to accelerate. This implies that once a country attains a specific quality of living, its carbon emission production will be increased. Countries with HDIs close to 0.6 are regarded "key country." They will follow the same development and pollution patterns seen by first-world nations after they exploit the existing infrastructure, raw resources, technology, and supply chain to eradicate poverty. WTN may supply items that benefit the next stage of human evolution in order to raise living standards, and trade also rise as a market mechanism.

8. Conclusion

WTN is a closely connected national network, mainly dominated by some countries. As the trade progresses, the world is developing towards multi-polarity. In this process, the United States continued to maintain its prominent position as a major player in global trade. In the past decade, China's dominance in the global trade market has risen significantly, surpassing the United States in exports.

Because WTN is highly connected, the number of separated communities is limited. The separated communities have similarities in geographic location and HDI. The differences in national trade within the community are gradually shrinking. With the development and change of the world, some high-tech countries have gradually added high-tech products and other high-value-added products in their own export trade, which makes them have different performance in terms of the carbon footprint from their exports. Many third-world countries or developing countries still mainly export high-carbon emission products, which actually reflects the unbalanced development of the world's technological level.

This disparity in global emissions and commerce is at the root of why the international climate change agreement is (and will remain) divisive. The world's richest country has half of the world's population and accounts for 86 percent of CO_2 emissions. It is obvious that we must decrease the emissions of high-income lifestyles in order to enhance global income and living standards (particularly for the poorest half) while minimizing climate change. Finding compatible strategies to eliminate this inequity is one of the century's most difficult challenges.

Strategic market forces in international trade agreements appear to have played a role, and improved environmental policies for multinational corporations in underdeveloped nations may assist reduce environmental degradation (Aller, Ductor & Herrerias, 2015). Policies fostering the transition from heavy industry to light industry and/or service sectors may contribute to improving environmental quality. Economic growth policies may support countries in decoupling from emission levels. Policymakers and supply-chain need to rethink trade, manufacturing, and logistics in developing countries. The political trade agreements should be re-negotiated to allow developing countries to take the lead.

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