Analysis of Global Trade Competition Pattern of New Energy Vehicles and Fuel Vehicles based on Multi-Layer Network

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***Abstract*—** *Use the 2023 global trade export data of new energy vehicles and fuel vehicles to build a multi-layer network of global new energy vehicles and fuel vehicles (including inter-country trade relationship networks and competition relationships networks), and use this network model to analyze new energy vehicles and fuel vehicles The market competition landscape at the trade level is analyzed, and the application of multi-level exponential random graph model (ERGM) in this field is discussed. The results show that the global trade network of new energy vehicles and fuel vehicles shows an obvious center-periphery structure. Some countries have significantly maintained import relationships with multiple countries in the auto trade, and some countries have shown that they are interested in multiple countries. The propensity of a country to engage in export trade. Further ternary structure analysis revealed the existence of stratification in the trade patterns between new energy vehicles and fuel vehicles. In addition, the network structure analysis of competitive relationships shows that there are direct trade competition relationships between only a few countries, which means that only a few countries play the role of key industrial countries in the automotive trade field.*

Keywords*— *Multilayered Network, Automobile Trade Network, Competition Network, Exponential Random Graph Model.

I. INTRODUCTION

Automobile trade is an important part of international trade, and its development trend not only reflects the global economic dynamics, but also indicates the direction of technological innovation and industrial development[1]. Its background can be traced back to the early 20th century, with the rapid development of the automobile industry, international trade has gradually risen. The purpose of automobile trade is to optimize the allocation of resources, meet the market demand for automobiles and related products through trade between different countries, and promote the growth of the global economy. With the acceleration of globalization, automobile trade not only promotes the transfer and innovation of technology, but also promotes the progress of production technology and the reconstruction of industrial chain [2][3]. According to their comparative advantages, countries have formed a pattern of division of labor and cooperation in the fields of automobile manufacturing, parts production and design. In addition, the automotive trade is closely related to changes in international policies, environmental regulations and market demand[4].

In recent years, with the enhancement of consumer awareness of environmental protection and the emphasis of policies on sustainable development, the trade volume of new energy vehicles has been rising, at the same time, the market of traditional fuel vehicles still maintains a certain demand, which reflects the transformation of the market structure and the change of consumer preferences. This not only reflects the diversity of market demand, but also promotes cooperation and competition among countries in the automobile trade[5]. At present, the research on automobile trade mainly includes two research directions: new energy automobile trade, which mainly focuses on the application of new technology and market expansion[6][7]; In the traditional fuel vehicle trade, relevant studies have discussed trade barriers, market share changes and so on[8]. Combining these two directions, this paper will discuss the current global trade competition pattern of new energy vehicles and fuel vehicles from the perspective of multi-layer networks.

In the pattern of trade competition, the status and role of the same country in different trade may change, which often leads to new structural characteristics of trade structure. Therefore, in order to deeply analyze the influencing factors of trade network, it is particularly important to establish a suitable empirical model. Among them, quadratic assignment program (QAP) and exponential random graph model (ERGM) are two commonly used methods, but QAP analysis method has some shortcomings compared with ERGM[9] [10][11][12][13]. First, Mao Yang used the QAP method to discuss the influential factors of the global new energy vehicle trade network, such as reciprocity, network density and economic scale, but did not combine the network structure with some external factors. The reason is that QAP method fails to consider the influence of network structure such as ternary structure and endogeneity[14]. Secondly, Yiwen Deng believes that metal resources play an indispensable role in the field of automobile manufacturing, and the formation and evolution of the global metal value flow network are influenced by both endogenous and exogenous mechanisms. In order to explore these drivers in depth and overcome the single-dimensional limitations of quadratic allocators (QAP) in analyzing networks, the exponential random graph model (ERGM) can be applied to enrich the application of complex network theory in this area[15].

In general, existing studies usually discuss new energy vehicles and traditional fuel vehicles respectively from the perspective of network analysis, but lack a systematic and comprehensive analysis framework. Research on the construction of multi-layer frameworks based on complex networks and the exploration of the competitive relationship between the two types of automobile trade between different countries is relatively weak, which fails to fully reveal their potential connections in the global automobile trade network. Based on this, this paper analyzes the global trade competition network of new energy vehicles and fuel vehicles through the multi-layer network theory, filling the gap in the comprehensive analysis of the two types of vehicles in the existing research. This paper introduces the calculation method of cross-product competition intensity, quantifies the competition relationship between the two types of vehicles, and identifies the important factors affecting the trade competition network through the analysis of multi-layer network influencing factors.

II. DATA SOURCES AND NETWORK CONSTRUCTION

2.1 Data sources:

This study selected data from the United Nations Trade Database (UN Comtrade) to build a global automobile trade network at two network levels and applied a threshold to the data to ensure that only the most relevant connections were retained while preserving the network structure[16]. This procedure also helped to ignore countries that did not contribute much to trade but increased the degree of reciprocity. The threshold for retaining trade relations was 0.01% of total trade. This threshold was determined by applying a threshold to review the proportion of world trade retained to ensure that the network represented the majority of global trade. The 0.01% cut retained 96% and 94% of world trade for new energy vehicles and fuel vehicles, respectively, with 96 countries for new energy vehicles and 121 countries for fuel vehicles.

This paper selects 2023 as the research year, and selects eight types of new energy vehicles with HS codes of 870220, 870230, 870240, 870340, 870350, 870360, 870370, and 870380 in UN Comtrade. Eight types of fuel vehicles with HS codes of 870210, 870321, 870322, 870323, 870324, 870331, 870332, and 870333 are selected as the research objects. The GDP per capita data (in US dollars) can be obtained by visiting the World Bank website. In order to obtain more accurate estimation results, we logarithmize the GDP per capita. The data of trade distance network and common language network come from the CEPII database.

2.2 Network construction:

A multilayer network is a complex network structure composed of multiple single-layer networks. Each single-layer network represents a level, and the layers are interconnected through connections of various attributes and types[17]. This network structure goes beyond the single property limitation of a single node and edge, and can contain different types of nodes and their various connection methods, thereby showing the interactions and dependencies between different sub-networks. It provides a more powerful tool for understanding and analyzing complex systems with multiple attributes.

This paper uses the multi-layer network theory framework to analyze the trade relationship and trade competition relationship between new energy vehicles and fuel vehicles among countries. The new energy vehicle trade and fuel vehicle trade are constructed as single-layer networks respectively, and the cross-category trade competition relationship between different countries of new energy vehicles and fuel vehicles is used as the inter-layer relationship (trade competition network), so as to construct a multi-layer network structure of the trade relationship and competition relationship between new energy vehicles and fuel vehicles among countries. The specific construction process is as follows:

First, at the level of new energy vehicle trade network, this study reveals the flow direction of new energy vehicle trade by analyzing the trade relationship of new energy vehicles, and builds A new energy vehicle trade network (recorded as directed network A) accordingly. This network is a single-layer network, with countries as nodes in the network, and the trade between countries is represented by edges, reflecting the import and export relationship between them. Secondly, from the perspective of the trade of fuel vehicles, this study analyzes the trade relations between countries to reveal the trade flow of fuel vehicles. Based on this, a fuel vehicle trading network (referred to as directed network B) is constructed. Finally, combining the two dimensions of new energy vehicles and fuel vehicles, a trade competition network of new energy vehicles and fuel vehicles (recorded as undirected network X) is constructed based on the trade competition relationship between them. The trade competition network is a binary network, which contains two types of nodes, representing new energy vehicles and fuel vehicles trading countries respectively. A connected edge between nodes of different classes indicates a competitive relationship between the two countries, while there is no connected edge between nodes of the same country. The final trade competition network connects the single-layer new energy vehicle trade network with the fuel vehicle trade network to form a multi-layer network (Figure1).

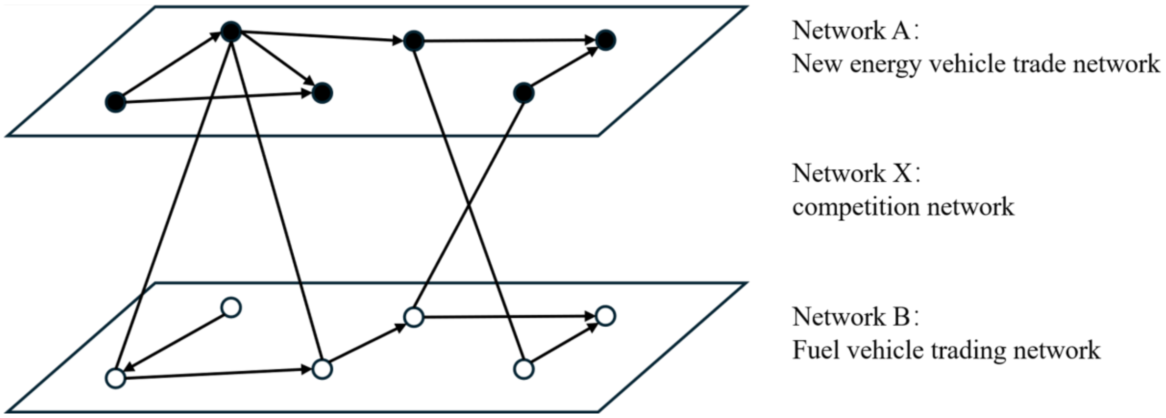


FIGURE 1: Schematic Diagram of the Global Trade Competition Network for New Energy Vehicles and Fuel Vehicles

III. DESCRIPTIVE ANALYSIS OF NETWORKS

3.1 Centrality analysis:

According to the above data, a network model is established and its structural characteristics are investigated. The calculation method of network centrality and its explanation are shown in Table 1.

TABLE 1
NETWORK CENTRALITY AND INTERPRETATION

Network indicator	Formulation	Explanation
Out and degree centrality	$C_{in}(i)=\frac{\sum_{j=1;i\neq j}^{n}x_{ij}}{n-1}, C_{out}(i)=\frac{\sum_{j=1;i\neq j}^{n}x_{ij}}{n-1}$	Represents the ability of a node to generate trade relationships with other nodes
Intermediation centrality	$C_B(i)=\frac{2\sum_{j=1;k=1;j\neq k,j<k}^{n}\frac{d_{jk}(i)}{d_{jk}}}{(n-1)(n-2)}$	Represents the ability of the node to control the trade path in the network

According to the above formula, the centrality index of each country is measured and the top five countries in each index are listed in Table 2. European countries dominate the top rankings, indicating that they play an important role in the global automotive trading countries. This is mainly due to the fact that many European countries, due to their special geographical location and developed trade infrastructure, have become hubs connecting different regions, especially in the transnational supply chain and logistics system. At the same time, policy coordination and economic integration within the EU have enabled European countries to efficiently coordinate their cooperation with other countries and regions in international trade, thus enhancing their influence in global trade flows[18]. Therefore, the high ranking of European countries in the centrality indicators reflects their central position among the global automotive trading countries.

The centrality of exportation reflects its activity in the export activities of the automotive trade and its key role in the global automotive supply chain. With advanced technological advantages and strong production capacity, Germany, China, Japan and South Korea are the most active countries in the export of new energy vehicle trade and fuel vehicle trade, and have established direct trade links with many countries. From the perspective of import centrality, European countries rank in the forefront of new energy vehicles and fuel vehicles trading countries in the world, showing strong import attraction and excellent global automotive supply chain integration capabilities. It is worth noting that the value of inbound centrality and the gap between countries is smaller than that of outbound centrality, indicating that there is a clear asymmetry in the import and export structure of the global automotive trading countries - that is, the source of imports is relatively concentrated, while the export market is more widely distributed.

TABLE 2
RANKING OF TOP FIVE COUNTRIES FOR AUTOMOBILE TRADE CENTRALITY

Type	Country	Out-degree Centrality	Country	In-degree Centrality	Country	Betweenness Centralit
New Energy Vehicles	Germany	0.716	Germany	0.232	Germany	0.112
	Japan	0.600	Belgium	0.200	Japan	0.054
	China	0.579	France	0.189	China	0.029
	United Kingdom	0.463	United Kingdom	0.179	Belgium	0.028
	South Korea	0.389	Italy	0.179	United Kingdom	0.026
Fuel Vehicles	Germany	0.550	Germany	0.267	Germany	0.121
	Japan	0.542	Belgium	0.200	United Arab Emirates	0.067
	China	0.400	France	0.192	Japan	0.064
	South Korea	0.392	United Arab Emirates	0.192	United States	0.035
	United States	0.367	Italy	0.183	Mexico	0.028

Betweenness centrality reflects the control a country node has over the trade paths in a network. Both Germany and Japan are ranked among the top five in the two automotive trade networks, playing a crucial hub role in these trade networks. This is not only due to their significant position in trade volume but also to their geographic location, economic strength, and trade policies, which together make these two countries key "bridges" connecting different nations and regions [19].

3.2 Core-Periphery Analysis:

The core-periphery structure was originally developed as a theoretical framework to explain the uneven economic development of regions, but it is now widely applied to describe various network structures. This structure refers to a network formed by numerous interconnected entities, where the nodes in the core are tightly connected, while the nodes in the periphery are relatively scattered. In other words, the central nodes of the network play a significant role, while the peripheral nodes occupy a relatively secondary position. This paper uses the core-periphery structure model developed by Borgatti to analyze the core-periphery structure in global new energy vehicle trade and conventional vehicle trade networks[20].

Using the core-periphery structure algorithm in UCINET software, we can calculate the core degree of each node in the network, which reflects the node's position in the trade network. The higher the core degree, the more important the node is in global trade. Based on the core degree values and in reference to relevant literature, we can categorize countries in the global automotive trade network into three levels: countries with a core degree greater than 0.2 are considered core countries, countries with a core degree between 0.1 and 0.2 are classified as semi-peripheral countries, and countries with a core degree below 0.1 are categorized as peripheral countries[7].

TABLE 3
CORE-PERIPHERY ANALYSIS OF GLOBAL AUTOMOBILE TRADE

Type	Core Country	semi-core country
New Energy Vehicles	Germany, South Korea, Japan, China, Slovakia, Hungary, United Kingdom, Belgium, Spain, Sweden, Czech Republic.	United States, France, Italy, Turkey, Poland, Austria, Netherlands.
Fuel Vehicles	Germany, Spain, France, Slovakia, Belgium, Italy, Hungary, Czech Republic, Japan, United Kingdom, Austria, Turkey, South Korea.	United States, Sweden, China, Netherlands, Romania, Morocco, Poland, Portugal.

The core-periphery analysis in Table 3 shows that the global trade network of new energy vehicles and fuel vehicles shows a clear core-periphery structure, and there are significant differences between the two. The number of core countries in the new energy vehicle trading countries is 11, which is reduced from the 13 core countries in the fuel vehicle trading network. Nine countries, including Germany, South Korea and Japan, are core countries in both automotive trade networks, thanks to their combined advantages in terms of automotive industry base, technological innovation, policy support and market demand. As a global automotive manufacturing power, Germany occupies an important position in the new energy vehicle and fuel vehicle trade network. This position is mainly due to the great contribution of its automotive industry to the national economy, as well as its continued leadership in technological innovation. It is with these advantages that Germany has been able to maintain its central position in the global automotive trade; South Korea and Japan each have unique competitive advantages in the field of fuel vehicles. South Korea is known for its advanced hybrid technology, excellent fuel efficiency and continuous technological innovation; Japan, on the other hand, has won the favor of global consumers with its high level of engine and transmission technology, excellent fuel economy, high warranty rate, as well as user-friendly design and excellent after-sales service. At the same time, traditional car manufacturers in both countries are actively transitioning to electrification; Slovakia stands out for its world-leading car production per capita and the significant contribution of the automotive industry to GDP [21]. Known as the "European law", Hungary has a strong car manufacturing and supply chain system, which has attracted many of the world's top car manufacturers to set up factories here. Belgium, with its superior geographical location and policy environment, has become an important hub for Chinese new energy vehicle exports to Europe. With its strategic location in Europe, Spain has the potential to become a "transit point" for the new energy vehicle industry. The UK has demonstrated in the field of new energy vehicles.

China and Sweden are both core countries in the new energy vehicle trading countries. China's rise is mainly due to the government's policy support, the growth of market demand, and the high importance of environmental protection [22].With its huge market size and high consumer acceptance of new technologies, China has quickly become the world's largest market for new energy vehicles. At the same time, Sweden has successfully promoted the widespread popularity of new energy vehicles due to its long-term advocacy of environmental protection concepts and the implementation of positive government incentives [23]. However, in the trade of fuel vehicles, China is relatively weak in technology research and development and brand influence, and has not yet formed a global dominant position; Sweden's fuel vehicle market is small and is shrinking in the context of the rise of new energy vehicles. Therefore, the two countries have not yet become core countries in the field of fuel vehicles. In contrast, Turkey, Italy and Austria occupy a central position in the fuel vehicle trading network, mainly due to their strong vehicle manufacturing capabilities and mature market base. However, the policy support, technology research and development and market development in these countries in the field of new energy vehicles are relatively lagging behind. Although they have made some progress in new energy vehicles, their market penetration is still low, and the electrification transformation process is slow, so they are still in a semi-core state.

3.3 Competitive Relationship Analysis:

Since competition is mutual, its measurement indicators are usually considered undirected. In the network construction of this article, it is mentioned that there may be cross-product competition in automobile trade between countries with different energy forms. In order to quantify this cross-product trade competition, this study draws on previous methods for quantifying market competition to measure the intensity of competition between different countries and different energy forms in the same market in new energy automobile trade and fuel automobile trade [24][25][26]. The specific method is as follows:

$$W_{ij}^{\alpha\beta} = \sum_{c}\left\{\left(\frac{H_{ic}^{\alpha}}{H_{w}^{\alpha}} \times \frac{H_{jc}^{\beta}}{H_{w}^{\beta}}\right) \times \left[1 - \frac{\left|\left(H_{ic}^{\alpha}/H_{i}^{\alpha}\right)-\left(H_{jc}^{\beta}/H_{j}^{\beta}\right)\right|}{\left(H_{ic}^{\alpha}/H_{i}^{\alpha}\right)+\left(H_{jc}^{\beta}/H_{j}^{\beta}\right)}\right]\right\} \times 100 \quad (1)$$

The formula $W_{ij}^{\alpha\beta}$ represents the competitiveness intensity between two countries in cross−product export. Here, c is a common market country for both new energy vehicle (NEV) exporting countries and fuel vehicle exporting countries. α and β represent new energy vehicles and fuel vehicles, respectively. H_w^{α} and H_w^{β} denote the total trade volume of new energy vehicles and fuel vehicles. H_{ic}^{α} represents the export volume from country i to country c for new energy vehicles, and H_{jc}^{β} represents the export volume from country j to country c for fuel vehicles. H_i^{α} and H_j^{β} are the total export volumes of country i for new energy vehicles and country j for fuel vehicles, respectively. The cross-product competitiveness intensity formula consists of two main parts. The first part $\left(\frac{H_{ic}^{\alpha}}{H_w^{\alpha}} \times \frac{H_{jc}^{\beta}}{H_w^{\beta}}\right)$ measures the competitive trade share. A larger competitive share indicates higher competitive pressure between the two countries. The second part $\left[1 - \frac{\left|(H_{ic}^{\alpha}/H_i^{\alpha}) - (H_{jc}^{\beta}/H_j^{\beta})\right|}{(H_{ic}^{\alpha}/H_i^{\alpha}) + (H_{jc}^{\beta}/H_j^{\beta})}\right]$ measures the similarity in the export structure between the new energy vehicle exporting country and the fuel vehicle exporting country. The higher the similarity, the more intense the cross−product competition between the two countries. Thus, a larger value of $W_{ij}^{\alpha\beta}$ indicates a higher level of cross-product competition between the two countries.

TABLE 4
TOP 20 COUNTRIES IN TERMS OF TRADE COMPETITION INTENSITY BETWEEN NEW ENERGY VEHICLES AND FUEL VEHICLES.

Rank	New Energy - Fuel	Competitiveness Intensity
1	South Korea - Japan	0.164
2	South Korea - Mexico	0.140
3	Japan - Mexico	0.121
4	Japan - Germany	0.119
5	Japan - South Korea	0.103
6	South Korea - Canada	0.099
7	Canada - Mexico	0.096
8	Japan - Canada	0.085
9	Germany - Japan	0.079
10	South Korea - Germany	0.063
11	Germany - Mexico	0.053
12	Canada - Japan	0.052
13	Germany - South Korea	0.048
14	Canada - South Korea	0.045
15	United Kingdom - Germany	0.044
16	Slovakia - Germany	0.039
17	Germany - Canada	0.037
18	China - Germany	0.031
19	Japan - United Kingdom	0.030
20	Japan - Italy	0.029

Table 4 shows the top 20 links between the exporters of new energy vehicles and fuel vehicles in 2023. As can be seen from the table, there is fierce trade competition between South Korea and Japan in the fields of new energy vehicles and fuel vehicles, which means that the export destinations of the two countries' automobiles are highly overlapped. In other words, some countries import new energy vehicles from South Korea and fuel vehicles from Japan at the same time. When the export volume of one party changes, the export volume of the other party will also be affected. This interconnected trade relationship shows that South Korea and Japan compete fiercely in the same market, and the export performance of the two countries is often driven by similar market dynamics.

Germany, Japan and South Korea have a high level of competition in the automobile trade, which is mainly due to their common technological advantages and global strategic layout in the automobile industry, and this competition is becoming more and more intense with the transformation of the global automobile industry. The German automotive industry is known for its precision engineering, advanced manufacturing processes and top design concepts, making it a global synonym for quality and innovation. In contrast, the automotive industries of Japan and South Korea occupy an important position in the global market with efficient production models, excellent fuel efficiency and excellent reliability. They have shown significant advantages in mass production and cost control, especially in the low-end market and bulk consumer goods sector, and have successfully attracted a large number of consumers with their products' high cost performance and excellent durability. In addition to the technical competition, the global market strategy is also an important factor in the automobile trade competition of the three countries[27]. The automobile brands of the three countries have highly overlapping layouts and expansion strategies in many key markets around the world, especially in Europe, the United States, Asia and emerging markets, which have launched fierce market share competition. German companies usually occupy mature markets through high-end positioning and brand effect, while Japan and South Korea have successfully occupied price-sensitive markets with strong production capacity, advanced manufacturing technology and low production costs. Through large-scale production and efficient supply chain management, they are able to offer cost-effective models that meet consumers' demand for a balance between price and quality, especially in emerging markets and the low - and mid-range markets. Through cooperation with local enterprises, the establishment of production bases and research and development centers, the three countries have continuously optimized the supply chain and increased market penetration, forming an all-round competitive landscape.

Since the 1980s, Mexico has played an increasingly important role in North American automotive manufacturing. Its geographical proximity to the United States, coupled with lower production costs and higher production efficiency, makes Mexico an important investment destination for global automotive assemblers (including multinational companies from Europe, Asia and the Americas) and their suppliers land. These factors have allowed Mexico to occupy a key position in the global automotive industry supply chain, especially in meeting the needs of the North American market, becoming an important hub in a highly competitive market. In addition, Mexico has further enhanced its competitiveness in the global automobile industry through trade agreements with the United States (such as the North American Free Trade Agreement, NAFTA), attracting a large amount of foreign investment. As the center of gravity of the global automotive industry gradually shifts to Mexico, the region's manufacturing and supply chain networks have also developed significantly, consolidating Mexico's position as the core base for automotive production and assembly in the North American market[28].

Canada's automotive industry benefits from its high value-added activities, competitive market environment, increasing technical requirements and high employment characteristics, which together promote the competitiveness of its automotive industry. In addition, Canada's stable political environment, developed manufacturing base, advanced technology and well-trained workforce all provide a solid foundation for the competitiveness of its automotive industry. Canada's regional competitiveness is also reflected in its ability to provide a sustainable environment that attracts businesses and residents, especially its close economic ties with the United States, which provides a huge market advantage for Canadian automotive exports[1].

IV. ANALYSIS OF FACTORS AFFECTING MULTI-LAYER NETWORKS

4.1 Exponential Random Graph Model:

The exponential random graph model (ERGM) is a statistical model used to analyze the edge relationships between nodes in a network and the mechanisms by which they are formed. Traditional network analysis methods view relationships as networks consisting of nodes and edges, and different conclusions can be inferred by analyzing these networks[29]. In contrast, the exponential random graph model takes a different perspective, viewing the observed network as one of many possible network structures. The probability of its occurrence is affected by the structural effects of the network, node attributes, and covariate network factors. Among them, the structural effect is a key component of the ERGM framework, which can directly model the interdependence between nodes in the network[30]. Node attributes regard the formation of network connections as the result of the attributes of the participants themselves, thereby determining whether nodes with specific attributes are more or less likely to establish relationships[31]. Covariate networks refer to external variables that affect network structure and node relationships, such as language, geographic location, and other factors that may affect the connections between nodes[32].

According to Wang et al.'s multi-layer network extension of the ERGM model[33], the extension involves multiple network levels, including network level A, network level B, and meso-network X. The general form of the multi-layer ERGM model is:

$$P(A=a,X=x,B=b)=\frac{1}{k(\theta)}exp\sum_{Q}\left\{\theta_Q Z_Q(a)+\theta_Q Z_Q(x)+\theta_Q Z_Q(b)+\theta_Q Z_Q(a,x)+\theta_Q Z_Q(b,x)+\theta_Q Z_Q(a,x,b)\right\} \quad (2)$$

Where,

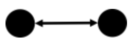
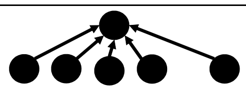
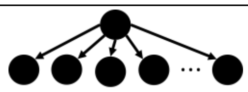
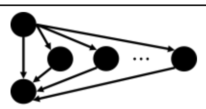
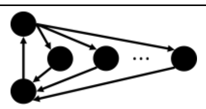
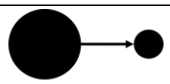
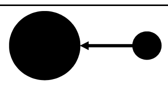
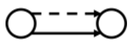
- $Z_Q(a)$ and $Z_Q(b)$re internal network statistics for network layer A and network layer B.
- $Z_Q(x)$is a network statistics of structural effects on meso-networks.
- $Z_Q(a,x)$ and $Z_Q(b,x)$are network statistics that involve configurations of a single network (either a or b) and a meso network (x), representing the interaction between the two networks.
- $Z_Q(a,x,b)$are the network statistics for the configurations that involve ties from all three networks.

MCMC-MLE (Markov Chain Monte Carlo Maximum Likelihood estimation) is usually used in ERGM (exponential random graph model) studies, but this study uses Bayesian inference method because it has more obvious advantages. MCMC-MLE first obtains a preliminary estimate through the pseudo-likelihood method, then compares the simulation results of multiple random networks with the results derived from the data, and finally adjusts the coefficients to increase the likelihood of matching between the two. Bayesian inference, on the other hand, incorporates more information by gradually updating the probabilities rather than simply comparing and adjusting the results of the analysis. Specifically, Bayesian estimation evaluates the probability of different values of various parameters in the analysis for a given observation data through MCMC, and uses a posterior distribution to reduce the uncertainty of the parameters. Compared with the maximum likelihood method, Bayesian inference usually achieves better results when dealing with complex data[34]。

4.2 Network Configuration:

Table 5 provides an overview of the configurations contained in each individual level and their economic interpretations, including reciprocity in the network, transitive closure, etc. Among them, reciprocity indicates whether there is a mutual export trade relationship between countries in the network; if the estimated value is positive, it means that the network tends to form a mutual export trade relationship. Among the node attributes, GDP (gross domestic product) is used as an example of economic interpretation to analyze whether a country with a larger market size and a higher economic level is more likely to form trade import and export relationships. Network covariates are used to determine whether other network relationships are conducive to the establishment of existing network relationships. For example, the distance network is included to test whether trade is inhibited by distance, as predicted by the gravity model of international trade[35]。

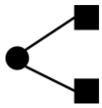
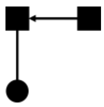
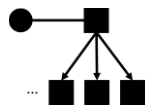
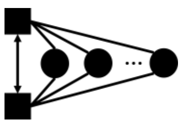
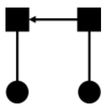
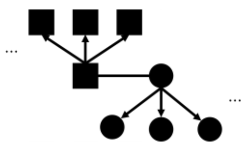
TABLE 5
SINGLE-LAYER NETWORK CONFIGURATION

Configuration Name	Configuration	Economic Explanation
Reciprocity		Two-way reciprocal relationships established between countries. They import and export to each other.
AinSA		The tendency of some countries in the network to trade imports with multiple countries.
AoutSA		The tendency of some countries in the network to export to multiple countries.
ATA-T		Some countries in a network are more likely to trade with countries that have multiple trading partners.
ATA-C		The tendency for trade to occur within subgroups of countries.
Sender Effect		Is it true that the stronger a certain attribute is, the easier it is to conduct export trade?
Receiver Effect		Is it true that the stronger a certain attribute is, the easier it is to conduct import trade?
Covariate Network		Whether other network relationships are conducive to the establishment of trade relations between countries.

Note:* ● *represents the national node.

When exploring multi-level configurations, we focus on the interactions between different network levels, including the new energy vehicle trade relations between countries, the fuel vehicle trade relations, and the competitive relations between countries in automobile trade. Table 6summarizes these configurations in detail and provides corresponding economic explanations, mainly referring to the research of[36]. Through these explanations, we can better understand the competitive relations between countries in the trade of new energy vehicles and fuel vehicles, and how these relations affect the competitive landscape of global automobile trade.

TABLE 6
MULTI-LAYER NETWORK CONFIGURATION

Configuration Name	Configuration	Economic Explanation
XStar2A		Do some countries in the network establish trade competition relationships with multiple countries?
In2StarAX		Countries with high levels of competition tend to establish import relationships in international trade.
AAoutS1X		Countries with high levels of competition tend to establish multiple trade export relationships in international trade.
ATXAXrecipority		The tendency for two countries with the same rivalry to induce trade.
L3XAX		The tendency for countries with high levels of competition to trade.
AoutasxAoutBS		When two competing countries have a large trade export relationship, will it cause the other country to export a large amount of trade?

Note:* ● *represents a country-level node for automobile trade of one energy type,* ■ *represents a country-level node for automobile trade of another energy type.

V. RESULTS

5.1 ERGM estimation results:

All estimation procedures in this article are performed using MPNet software[37]. Under the conditions of network configuration and other effect parameters set by a specific model, parameter estimates can reflect the probability of occurrence of network configuration. A positive and significant configuration parameter indicates that the structure is observed in the test network more frequently than chance.

TABLE 7
ERGM ESTIMATION RESULTS OF NEW ENERGY VEHICLES

Configuration Name	Bayesian estimation [posterior mean (posterior standard deviation)]		
	Model 1	Model 2	Model 3
Reciprocity	1.121 (0.316)*	1.416 (0.259)*	1.231 (0.004)*
AinSA	-0.575 (0.182)*	1.040 (0.160)*	1.202 (0.004)*
AoutSA	1.087 (0.251)*	2.011 (0.197)*	1.981 (0.002)*
ATA-T	1.838 (0.162)*	0.399 (0.113)	0.320 (0.004)*
ATA-C	-0.263 (0.067)*	-0.072 (0.051)	0.008 (0.009)
GDP ReceiverA		3.958 (0.694)*	-0.156 (0.001)*
GDP Out2StarA		0.057 (0.002)*	0.080 (0.002)*
Common Language Network		-0.196 (0.137)	0.167 (0.001)*
Distance Network		-0.020（0.009）*	-0.036（0.009）*
Xstar2A			-0.207（0.003）*
In2StarAX			-0.007（0.003）*
AAoutS1X			0.036（0.004）*
ATXAXrecipority			0.595（0.006）*
L3XAX			0.002（0.00005）*
AoutasxAoutBS			0.035（0.0002）*

Note: * Significant effect.

In Table 7 we specify the impacts in increasing order of complexity. Model 1 only measures the structural effect of the new energy vehicle trade network, Model 2 adds attribute variables and covariate networks, and Model 3 adds the fuel vehicle trade network that competes with new energy vehicles to the former.

Model three covers both the structural effects of model one and the attribute variables and covariate network of model two. Using this model we can effectively analyze the trade competition network based on the interaction of various factors. In Model 3, the estimated coefficient of reciprocity is 1.231, indicating that there is significant reciprocity in global new energy vehicle trade, which means that many countries import and export to each other in the field of new energy vehicle trade. This reciprocity reflects the interdependent relationship between many countries in the international trade network and promotes cross-border commodity flows and economic cooperation. The estimated coefficient of AinSA is 1.202, which shows that there are obviously some countries that maintain trade and import relations with multiple countries at the same time. On the other hand, the estimated coefficient of AoutSA2 is 1.981, which shows that in the global automobile trade network, some countries have a significant tendency to trade exports to multiple countries. This phenomenon shows that these countries may have comparative advantages in some aspects and can become important supplier countries in the global automobile trade network, especially in the export of new energy vehicles and fuel vehicles. The ATA-T estimated coefficient is 0.320, further revealing a stratified trade pattern in which certain countries dominate the trade of new energy vehicles. This structural feature shows that in the global new energy vehicle trade network, there are obvious differences in the trade status of different countries. Some countries not only have advantages in exports, but also play an important role in imports, forming a global new energy vehicle trade. "hub" countries. The results of GDP attribute variables at the new energy vehicle trade network level show that rich countries are more likely to have multiple export relationships, but are less likely to be importers in this sector. This reflects the ability of larger wealthy countries to source domestically rather than rely on imports. For the covariate network parameters of new energy vehicles, the estimated coefficient of the common language network is 0.167, indicating that there is significant overlap between the new energy vehicle trade network and the common language network and has an important positive impact on it. This is because a common language is conducive to trade between countries, helps to reduce and solve problems that arise during the trade process, and is conducive to the formation of trade relations. The estimated coefficient of the distance network is negative, which shows that distance has a certain restrictive effect on the development of global new energy vehicle trade. This is mainly because the automobile trade mainly relies on sea transportation. Although the cost of sea transportation is relatively low, distance still imposes certain restrictions on trade. We find that the Xstar2A estimated coefficient is -0.207, indicating that only a few countries have established extensive competitive linkages across multiple markets. This finding further emphasizes the key role of industrial competition in measuring the competitive position and economic strength of a country or region within a specific industrial field, and also provides support for the existence of a core-periphery structure[38]. Specifically, in the new energy vehicle trade, only a few countries dominate and play a key role in the competition in the new energy industry. These countries usually have strong technological innovation capabilities, production scale advantages and market influence, thus occupying a key position in the competitive landscape of the global automobile industry. The estimated coefficients of AAinS1X and AAoutS1X are -0.007 and 0.036 respectively. It shows that key countries in the industrial field are more likely to have multiple trade and export relationships (positive and significant export trade), but are less likely to become trade importers (negative and significant import trade). This finding reveals the unique status and behavioral patterns of key industrial countries in the global trading system. Specifically, countries at key positions in the industrial chain usually have strong production capabilities, technological innovation capabilities and market influence, allowing them to occupy a dominant position in export trade. Especially in terms of high value-added and technology-intensive automotive products, these countries are able to meet global market demand and occupy important shares. However, these countries show lower dependence on import trade. This trade pattern reflects that key industrial countries prefer to pursue domestic self-sufficiency rather than rely on external supplies. This self-sufficiency strategy not only enhances their autonomy and competitiveness in the industry chain, but also reflects their control and resource allocation advantages in the global automobile industry chain. In addition, in the context of globalization, countries with the same competitive relationship often form upstream and downstream cooperative relationships in a certain field. This cooperation not only promotes similarities in types of export products but also deepens economic ties between countries. By estimating the reciprocal trade parameter with the same competitive relationship, we obtained an estimated value of 0.595, which indicates that countries with competitive relationships may have similar consumption habits and brand perceptions, thereby being more inclined to trade in the international market. contacts. The estimated coefficient of L3XAX is 0.002, indicating that countries with many competitive relationships are often more likely to establish close trade ties. This phenomenon shows that in the context of globalization, competition does not always lead to estrangement. Instead, it can promote trade links between countries, thereby achieving mutual benefit and win-win results. When a country builds a strong export network in international markets, other countries may feel competitive pressure. This is verified through the AoutASXAoutBS parameter, whose estimated value is 0.035, which shows that when a country builds a huge trade export system in the international trade market, other countries may face competition challenges. In order to maintain or enhance their position in the global market, these countries may increase exports to other countries to prevent the loss of market share.

TABLE 8
ERGM ESTIMATION RESULTS FOR FUEL VEHICLES

Configuration Name	**Bayesian estimation [posterior mean (posterior standard deviation)]**		
	Model 4	**Model 5**	**Model 6**
Reciprocity	1.670 (0.299)*	2.372 (0.242)*	2.524 (0.113)*
AinSB	-0.713 (0.136)*	1.293 (0.265)*	0.557 (0.225)*
AoutSB	0.868 (0.166)*	0.808 (0.329)*	2.100 (0.081)*
ATB-T	1.939 (0.113)*	1.648 (0.396)*	1.542 (0.243)*
ATB-C	-0.203 (0.068)*	-0.018 (0.171)	-0.104 (0.087)
GDP ReceiverB		-0.863 (0.425)*	1.729 (0.160)*
GDP Out2StarB		0.069 (0.030)*	0.529 (0.129)*
Common Language Network		-0.125 (0.375)	-0.121 (0.110)
Distance Network		-0.091 (0.108)	-0.673 (0.193)*
Xstar2B			-0.285 (0.089)*
In2StarBX			0.013 (0.092)*
ABoutS1X			0.062 (0.056)
ATXBXreciprority			13.059 (0.097)*
L3XBX			-0.002 (0.006)
AoutASXaoutBS			0.039 (0.014)*

Note: * Significant effect.

For fuel vehicles, the results are quite different (Table8). In Model 6, the estimated coefficient of reciprocity is 2.524, indicating that there is an obvious reciprocal trade relationship between countries in global fuel vehicle trade. This means that multiple countries import and export to each other in the field of fuel vehicles. This reciprocity facilitates the international flow of goods and promotes the development of transnational economic cooperation. The AinSB estimated coefficient is 0.557, indicating that in the global automobile trade network, some countries maintain significant trade and import relationships with multiple countries. This phenomenon reflects the key position of these countries in the global supply chain. They not only import automotive products from multiple source countries, but also meet domestic market demand through diversified import channels. This may be related to the country's large market size, diversified consumer demand and the complexity of the industrial structure. On the other hand, the AoutSB2 estimated coefficient is 2.100, indicating that some countries have a significant tendency to export to multiple countries in global automobile trade, and this trend is often closely related to the competitive advantages of these countries in automobile production and technology. The ATB-T estimated coefficient is 1.542, revealing the obvious layered structure in global fuel vehicle trade, with some countries occupying a dominant position in this field. This phenomenon reflects the asymmetry in the global fuel vehicle trade network and indicates that some countries may have strong automobile manufacturing industries and advanced technological levels, allowing them to dominate the global market. The estimated results of GDP attribute variables at the fuel vehicle trade network level are 1.729 and 0.529 respectively. This shows that economically wealthy countries not only tend to have more complex export relationships in the fuel vehicle trade network, but are also often important importing countries. This phenomenon shows that rich countries play a more complex role in the trade of fuel vehicles due to their higher level of economic development and industrial diversification. They not only export high value-added products to achieve economies of scale and scope, but also import to optimize resource allocation and reduce production costs to meet domestic market demand and maintain the integrity of the industrial chain. The distance network estimated coefficient is -0.673, indicating that geographical distance plays a certain restrictive role in global fuel vehicle trade. Although sea transportation is relatively economical in terms of cost, long transportation distances will still increase transportation time and risks, thus affecting the efficiency and reliability of trade. Longer distances can lead to higher transportation costs and require more time to complete transactions, thereby inhibiting the frequent occurrence of cross-border trade. The estimated coefficient of Xstar2B is -0.285, which implies that among many countries, only a few are able to establish extensive competitive ties. The ABinS1X estimated coefficient is 0.013, indicating that key countries in the fuel vehicle industry are more likely to have multiple trade import relationships. First of all, the complexity of the global supply chain of the fuel vehicle industry requires extensive cooperation among countries in raw materials, parts, and technology. Secondly, there may be complementary trade relations between key countries, that is, one country has comparative advantages in some links, while another country has advantages in other links. This complementarity promotes the formation of multilateral trade relations. The estimated coefficient of ATXBXrecipority is 13.059. In the fuel vehicle industry, competing countries have enhanced trade ties due to similar consumption habits and brand recognition. The estimated value of the AoutASXAoutBS parameter is 0.039, which shows that when a country establishes a strong export network in the field of international trade, other competitors may feel the pressure. In order to consolidate or enhance their competitiveness in the international market, these countries may strive to expand exports to other countries to avoid losing market share.

VI. CONCLUSION AND DISCUSSION

This paper mainly studies the global trade competition pattern of new energy vehicles and fuel vehicles. To this end, this paper regards the automobile trade network as a multi-level network, including the new energy vehicle trade network, the fuel vehicle trade network, and the cross-category trade competition relationship network between different countries. In this multi-level network, a few countries play the role of key industrial countries in the field of new energy vehicles. These countries tend to have multiple export trade relationships, but are unlikely to become trade importers. This shows that industrial powers prefer domestic self-sufficiency rather than relying on external imports. In the field of fuel vehicles, these key countries often have multiple trade import relationships. When a country establishes a strong export network in the international market, other countries may feel competitive pressure and increase exports to other countries to prevent the loss of market share. Overall, the global automobile trade pattern is jointly shaped by the trade network of new energy vehicles and fuel vehicles and their competition pattern. These networks and competition patterns are affected by many factors, including the country's economic strength, geographical environment, market demand, etc. These factors work together to form the current global automobile trade pattern.

The multi-layer ERGM method used in this paper has certain shortcomings. The model cannot handle weighted relationships and time series data, but it is full of unlimited possibilities in future research, especially when multi-layer network models and data sets are applied to different industries or different fields of the same industry. In addition, this method has the possibility of further development. It can conduct a more in-depth comparative analysis of different trade industries, so as to more accurately understand the trade pattern in the global economy.

This analysis can be further extended to all links of automobile trade. Although we currently focus on automobile trade, this study can be extended to all links from Research and Development design to final use. By expanding the multi-layer dataset to cover all links of the automobile global value chain, we will be able to study the trade patterns of countries in more depth. In this way, the analysis will be more comprehensive and help reveal the trade dynamics and investment patterns of different countries in the automobile industry.

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