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Evolution of New Energy Minerals Trade Pattern and Analysis of China's Status Evolution

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Abstract. Copper, cobalt, nickel as the key raw materials for the new energy automobile industry, the supply and demand of resources and international trade are largely affected by the world economy and political pattern, and the risks and vulnerabilities of the resource industry chain are highlighted. Using the method of complex network to analyze the trade network of three kinds of mineral resources from the perspective of industrial chain, the following conclusions are drawn: (1) the global trade network of three kinds of new energy minerals in the whole industrial chain all presents the characteristics of complexity and connection enhancement, and has the characteristics of the network of the small world; (2) China has become an important hub in the global trade network of copper, cobalt, and nickel, and has a stronger ability to control the trade of other countries.

Keywords: New Energy Minerals; Trade Pattern; Method of Complex Network; Mineral Resources Industry Chain.

1. Introduction

Strategic metal mineral resources have become a crucial material foundation supporting the high-quality development of China's strategic emerging industries[1]. Moreover, in light of the increasingly pressing environmental concerns, green and low-carbon initiatives have taken center stage in national development agendas, leading to a soaring demand for new energy strategic metal mineral resources such as copper, cobalt, and nickel[2]. Currently, global resource endowments of these new energy strategic metal minerals exhibit an uneven distribution[3]. As strategic emerging industries continue to advance, new energy strategic metal minerals will evolve into pivotal resources enabling countries worldwide to seize economic and technological innovation commanding heights; consequently intensifying international competition within this sector.

Generally speaking, the more complex the industrial chain is, or the more concentrated the key intermediate products are, the more vulnerable it is to shocks. With the deepening and complication of the international division of labor, the vulnerability of the global industrial chain itself has become more and more prominent, and it is highly sensitive to changes in the external environment[4]. The introduction of network analysis into trade analysis has been increasingly recognized by scholars, and studies have been carried out to analyze the pattern, spatial evolution and topological relationship of trade networks at different scales, such as global and regional [5-7], and to conduct in-depth research on the trade networks of agricultural products, minerals, natural gas, high-end manufacturing industries and other industries at the level of specific industries[8-10].

In the complex and changeable international situation, copper, cobalt and nickel, as the key raw materials of the new energy automobile industry, are largely affected by the world economic and political pattern of resource supply and demand and international trade, and the risks and vulnerabilities of the resource industry chain are prominent. Therefore, it is particularly important to identify the vulnerabilities and risks of the whole resource industry chain based on the global trade network.

2. Data and Model

2.1. Data

Considering the completeness of the data, we choose UN Comtrade as the source of global trade data. According to the different industrial chain of each mineral product, we choose different products as research objects in each link of the industrial chain. In the upstream link, copper ore and waste copper are selected as the research objects of copper industry chain. Cobalt ore is selected as the study object of cobalt industry upstream and nickel concentrate as the study object of nickel industry upstream. The research objects of each link are shown in Table 1.

Table 1. Copper, cobalt, nickel products

Industrial chain link	Production		HS code
Upstream	Copper	Copper ores and concentrates	2603
		Scrap copper	7404
	Cobalt	Cobalt ores and concentrates	760500
	Nickel	Nickel ores and concentrates	2604
Mid-stream	Copper	Matte	7401
		Coarse/anodized copper	7402
		Electrolytic copper/refined copper	7403
		Copper base intermediate alloy	7405
	Cobalt	Cobaltous sulfate	283329
		Cobaltous chloride	282739
		Electrolytic cobalt	810520
		Cobalt oxide	282200
	Nickel	Nickel and its products	7501~7508
Downstream	Copper	Powder	7406
		Bar	7407
		Wire rod	7408
		Board	7409
		Foil	7410
		Tube material	7411
	Cobalt	Lithium cobalt oxide	284190
	Nickel	Lithium-ion battery	850760

2.2. Model

Complex network analysis is used to study the trade evolution characteristics of copper, cobalt and nickel industry chain. Taking x_n to denote the trading countries and y_p to denote the specific products, where p=1, p=2, p=3 denote the upstream link, the midstream link and the downstream link, respectively, and t is the time of the study, which is 2010, 2016 and 2022 here, respectively.

$$A_{1,n,2010} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix}$$

Based on the matrix $A_{p,n,t}$, the global trade networks of upstream products, midstream products and downstream products of copper, cobalt and nickel in 2010, 2016 and 2022 were firstly visualized using Gephi software. Meanwhile, three indicators, namely degree centrality, weighted degree centrality and intermediary centrality, were used to measure the characteristics of each global trading country. In addition, the average degree and graph density metrics are used to measure the characteristics of the entire trade network.

(1) *Degree Centrality (D)*.In complex network modeling, the metric that describes the distribution of the number of connections of network nodes is known as degree, which is subdivided into in-degree (ID) and out-degree (OD). The in-degree represents the number of other nodes pointing to a particular node, responding to the diversity of imports of a particular node; similarly, the out-degree represents the number of other nodes pointing to a particular node, responding to the diversity of exports of a particular node.

$$D_i = OD_i + ID_i$$

$$OD_i = \sum_{j=1}^{l} r\,, r_j = \begin{cases} 1, a_{il} \neq 0 \\ 0, a_{il} = 0 \end{cases}$$

$$ID_i = \sum_{j=1}^{l} r\,, r_j = \begin{cases} 1, a_{li} \neq 0 \\ 0, a_{li} = 0 \end{cases}$$

(2) *Intermediary Centrality (BC).* In the complex network model, the intermediary center school is used to measure the degree of control of node countries over resources. The more intermediary positions a country (node) occupies, the more control it has over the resources, the more important it is, and the more control it has over trade between the other two countries (nodes).

$$BC_i = \sum_{(v,q)} \frac{D^i(v,q)}{D(v,q)}$$

3. Result

3.1. Evolution of Copper Trading Networks

In recent years, in the context of energy transition, the demand for copper as a key raw material for new energy automobile industry and other strategic emerging industries has been rising. At present, China has become the world's largest copper consumer, supply and demand mismatch is prominent. And in the case of insufficient domestic supply, from Chile, Mongolia and other copper-rich countries to import copper concentrate has become the main way to solve the contradiction between supply and demand, copper concentrate imported from these countries accounted for 60-80% of China's total copper concentrate imports. As a very important non-ferrous metal material, copper has a wide range of application value, and the status of copper trade in global trade is also very significant. However, from the perspective of the whole industry chain, there are differences in the properties and uses of copper upstream, midstream and downstream products, and there are certain differences in the international trade pattern.

As the world's top copper consumer, China mainly imports copper in the upstream. China mainly imports from Chile, Peru, two large copper reserves, while Kazakhstan, Mongolia as China's "One Belt, One Road" important partners and its copper trade transactions are relatively close, but in recent years the instability of the national policy of the resource countries, such as the Chilean workers strike

and other unforeseen circumstances, resulting in upstream copper supply instability Therefore, China needs to actively broaden its overseas resource sources to reduce the risk of resource supply disruption.

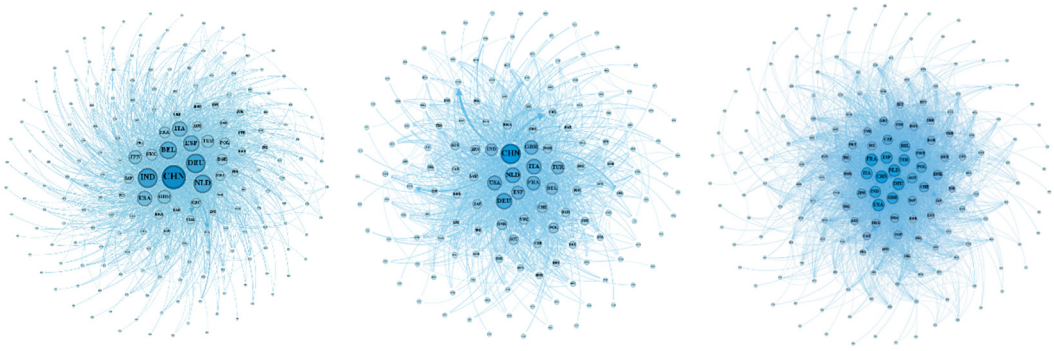

Figure 1. Copper Trade Network

China as the world's largest copper producer, in the upstream trade network in the import and export trade core status is significant, diversification features obvious, under the same conditions, to a certain extent, reduce the risk of resource supply cuts, the copper products trade security level continues to improve. For the United States, its upstream copper products import diversification is higher than its exports, for trade. In addition, from the weighted degree ranking can be seen, in the upstream copper trade network, the world's major copper output countries have more prominent trade capacity. Due to the uneven distribution and relative concentration of resources, upstream producing countries may rely on their own resource endowment and network status advantages to have a greater impact on the upstream trade network. Table 2 shows the change in the ranking of the degree centrality of the upstream link from 2010 to 2022, and it can be seen that the number of China's trading partners in the upstream link has always been in the lead, while the United States ranked relatively backward only in the import trade in 2016, which performed better.

Table 2. Copper Upstream Trade Network Center Degree Ranking

Ranking	2010			2016			2022		
	ID	OD	D	ID	OD	D	ID	OD	D
1	German	China	China	USA	China	China	China	China	China
2	USA	India	German	China	German	German	USA	India	India
3	China	German	India	South Africa	South Korea	Italy	UK	German	German
4	UK	South Korea	USA	German	the Netherlands	the Netherlands	German	the Netherlands	the Netherlands
5	Italy	Belgium	South Korea	Chile	Belgium	South Korea	Italy	Belgium	Belgium
6	French	the Netherlands	Italy	Italy	Japan	Belgium	the Netherlands	Spanish	Spanish
7	Spanish	Italy	Belgium	Belgium	Italy	Spanish	Spanish	Japan	Italy
8	Arabian	USA	the Netherlands	French	Spanish	India	French	Italy	USA
9	Canada	Spanish	UK	Spanish	India	Japan	Canada	Istanbul	Japan
10	the Netherlands	Japan	Spanish	Brazilian	Sweden	French	Austrian	USA	UK

Table 3 shows that in copper upstream trade, the trade influence of major copper-producing countries other than China is not prominent. China's trade influence for upstream copper has been steady at the top of the list, declining in 2022, but trade influence is still strong. Chile and the DRC, as the world's major copper producers, are significantly less influential in upstream trade, while Germany, France,

Italy and other copper-demanding countries have more prominent trade influence. The reason for this is that countries are committed to carbon emission reduction, the development of clean energy technology to promote the increase in demand for key metals represented by copper, resulting in a gradual increase in the trade influence of copper resource demand countries.

Table 3. Copper Upstream Trade Network Intermediary Centrality Ranking

Country	2010	2016	2022
China	1	1	4
Chile	58	38	25
Congo (DRC)	130	124	113
Japan	26	5	11
Russia	34	41	91
USA	4	10	15
Polish	54	20	22
Kazakhstan	21	74	57
Mexico	33	56	69
Australia	20	24	23
German	3	3	7
India	5	4	5
French	6	12	19
Italy	7	7	13
UK	8	18	17

The trade closeness of the copper midstream link is deepening, and China is a world leader in the number of trading partners in the midstream link, similar to the situation in the upstream link. This may be due to the number of trading partners and trade centrality of the upstream segment. As a result, China's risk of resource disruptions in the midstream is relatively low compared to other countries, and the level of trade security for copper products is high. Similarly, as in the case of the upstream, Germany's number of trading partners is more diversified. The United States' trade diversification is stable, but decreases in 2022 compared to other years.

In copper midstream trade, the trade influence of major copper-producing countries other than China is not prominent. China's trade influence on copper midstream products is more stable than that of the upstream, and it is in a leading position in the world. The U.S. has a more prominent trade influence on the midstream than on the upstream. Japan, as one of the major copper-producing countries, also shows a fluctuating upward trend in its midstream trade influence. Similar to the upstream segment, some European countries have a stronger trade influence on the midstream segment than the producing countries.

Compared with the upstream and midstream segments, the number of countries involved in the downstream trade network and the number of transactions have increased significantly, and the complexity of the network has increased. In 2010, the degree of downstream trade diversification of major copper-producing countries was higher, but the degree value of major copper-producing countries, except for China, showed a fluctuating downward trend. However, the degree of downstream trade diversification of European countries with strong downstream demand, such as Germany and Italy, shows a fluctuating upward trend, which indicates that these countries are paying

more attention to the diversity of resource import and export, increasing the security of their own resources, and reducing the risk of supply disruption.

The trade influence of copper-producing countries in the copper downstream trade network is significantly lower than that of copper-demanding countries, and slightly different from the upstream and midstream, the trade influence of the South African countries in the downstream copper trade can be seen. Similar to the upstream and midstream, the downstream trade influence of some European countries is significant. Taken together, the complexity of copper downstream trade is significantly stronger than the upstream, midstream links, in addition to China, the United States, the world's major copper-producing countries for the copper industry chain influence is weaker than the influence of demand countries.

3.2. Evolution of Cobalt Trading Networks

As a basic material for economic and social development, cobalt resources are not only utilized in many industries such as aerospace, machinery manufacturing, electric power, communication and construction, but also widely used in a series of strategic emerging industries and high-tech fields. At present, the distribution of cobalt resource endowment is uneven, countries around the world in the supply and demand for geographic field characteristics, with the new technological revolution and industrial change continues to advance, cobalt resources will become the core resources of the countries to seize the commanding heights of the global economy and the heights of the innovation capacity, the industry, the international competition is becoming more intense.

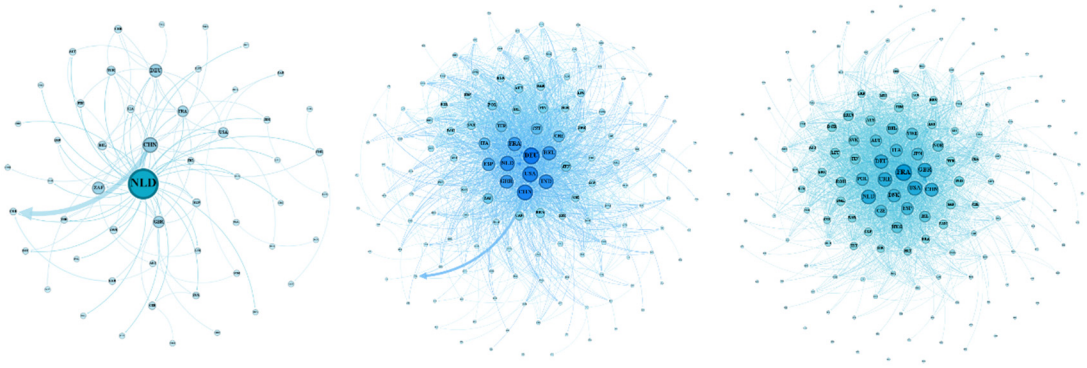

Figure 2. Cobalt Trade Network

During the period of 2010~2016, the dominant position of China and the United States in the number of trading partners was replaced by the Netherlands, the United Kingdom and other European countries, and the European countries represented by the Netherlands and the United Kingdom have been increasing the importance of cobalt import and export diversification.During the period of 2016~2022, the Netherlands has been in the leading position in the number of trading partners, and China alternately in the ranking of the top. In the global trade of cobalt products, the larger the weighted degree of a country indicates that the country's share in international trade is higher, indicating that the country's trade capacity is stronger, and from the data of the weighted degree in 2022, DRC, as a global cobalt production country, has the most prominent share of the trade share and stronger trade capacity. In addition to the DRC, the trade capacity of the other cobalt-producing countries is also more prominent in the upstream segment.

With the exception of China and the United States, the major cobalt-producing countries' trade influence in the upstream segment is significantly weaker than that of the cobalt-demanding countries. China, as a major cobalt concentrate producer, has seen its trade influence decline after 2016, but remains strong. European countries, such as the Netherlands, the UK and Germany, have strengthened their control over resources.

Table 4. Cobalt Upstream Trade Network Degree Ranking

Ranking	2010			2016			2022		
	ID	OD	D	ID	OD	D	ID	OD	D
1	USA	India	China	UK	the Netherlands	the Netherlands	China	the Netherlands	the Netherlands
2	German	USA	German	USA	China	China	UK	China	China
3	UK	China	Italy	China	South Africa	UK	German	South Africa	German
4	Congo (DRC)	German	USA	Belgium	Czech	USA	South Africa	German	South Africa
5	China	Mexico	UK	the Netherlands	Belgium	South Africa	the Netherlands	French	UK
6	French	French	French	Japan	South Korea	Belgium	French	USA	French
7	South Africa	Italy	India	South Africa	French	Seychelles	USA	Istanbul	USA
8	Belgium	Canada	the Netherlands	Congo (DRC)	Spanish	Japan	Belgium	Spanish	Belgium
9	Canada	Czech	Belgium	Seychelles	India	Czech	Sweden	Chile	Istanbul
10	Congo (Brazzaville)	South Africa	Spanish	German	UK	South Korea	Congo (DRC)	Czech	Spanish

The midstream segment shows a similar pattern to that of the upstream segment, with countries with more trading partners in the upstream having the same situation in the midstream. In particular, China's trading partnerships in the midstream are more stable and higher ranked, while China places more emphasis on import diversification than export diversification, suggesting that it is expanding its sources of imports in order to prevent the risk of supply chain disruptions abroad. European countries in the midstream have declined in the ranking of trading partners compared to the upper reaches, while the United States has remained relatively stable.

In terms of trade influence in the midstream segment, the U.S. has been in the lead, but is overtaken by Germany in 2022. China's trade influence is relatively stable and also in the upstream position. The world's major cobalt-producing countries have insufficient trade influence in the midstream, in line with the upstream situation. The trade influence of European countries has been climbing, especially Germany and the Netherlands, which have been on an upward trend.

The trade partnership in cobalt downstream trade has a large change, in 2010, Mexico, Brazil, Denmark and other countries have more export trade partnerships, but in 2016 ~ 2022, there is a large change, the ranking is not high. China has always paid more attention to the diversification of import sources, and the ranking of import trade partnerships has always been at the top. At the same time, after 2010, China has been strengthening its export trade with other countries, and the degree of export diversification has been deepening. The relatively high ranking of import trade partnerships among the world's major economies suggests that countries are striving to diversify their sources of imports and secure resources abroad.

3.3. Evolution of Cobalt Trading Networks

In recent years, as countries continue to develop new energy vehicles and advocate high nickel batteries, the demand for nickel resources continues to increase, and the sustainable development and utilization of nickel resources has become a global concern. However, nickel resource endowment distribution is uneven, countries around the world in the supply and demand for geographic field characteristics, with the new technological revolution and industrial change continues to advance, cobalt resources will become the countries to seize the global economic commanding heights and the

innovation capacity of the commanding heights of the core resources, the industry, the international competition is becoming more and more intense.

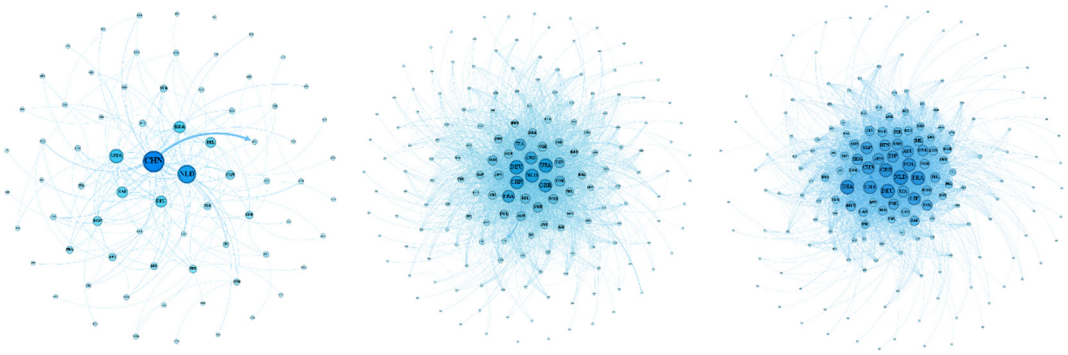

Figure 3. Nickel Trade Network

In terms of upstream trade partnerships, China has been ranked relatively high in this indicator, indicating that China has a relatively rich number of partners in upstream nickel ore trade and a high degree of import and export diversification. In addition, the weightedness indicator shows that although the Philippines does not have the best ranking in terms of the number of trading partners, as a nickel ore producer, its influence in the upstream trade is also relatively strong.

Evolution of national control capacity in the upstream nickel trade network. It can be seen that the trade control ability of the main nickel producing countries is relatively strong, especially China, which is in the leading position in the upstream trade network of nickel ore. While the demand countries represented by Germany and the UK show fluctuating and changing trends in their trade control ability for nickel ores, and in general, the trade control ability is relatively weak compared with that of the producer countries.

Table 5. Nickel Upstream Trade Network Degree Ranking

Ranking	2012			2016			2022		
	ID	OD	D	ID	OD	D	ID	OD	D
1	USA	China	China	USA	China	China	USA	China	China
2	Canada	Canada	Canada	China	Canada	USA	China	the Netherlands	the Netherlands
3	German	German	German	UK	USA	Canada	Canada	Belgium	USA
4	South Africa	South Africa	South Africa	Suomi	German	German	Brazilian	Singaporean	Brazilian
5	Indonesia	South Korea	USA	Japan	South Korea	Suomi	UK	Brazilian	German
6	Australia	Denmark	South Korea	Canada	Suomi	South Africa	the Netherlands	German	South Africa
7	the Netherlands	Vietnam	India	German	French	South Korea	German	Suomi	Belgium
8	Suomi	North Macedonia	French	Australia	Malaysia	Japan	India	Australia	Singaporean
9	China	Italy	the Netherlands	South Africa	South Africa	French	Guatemala	Istanbul	Canada
10	French	USA	Suomi	Suomi	Spanish	Australia	Canada	Spanish	Suomi

The trade control ability of the major nickel producing countries is relatively strong, especially China, which is in the leading position in the upstream trade network of nickel ores. While the demand countries represented by Germany and the United Kingdom show fluctuating changes in their trade

control ability for nickel ores, and in general, the trade control ability is relatively weak compared with that of the producer countries.

In terms of the national control of the nickel midstream trade network, the country is relatively stable from 2012 to 2016, and although China's ranking in this indicator declines, the value increases, indicating that China's trade control of the nickel midstream has increased; during this period, the Netherlands' control of the nickel midstream trade has increased significantly. In 2016-2022, the intermediary centrality ranking changes considerably, Italy, Sweden and other European countries' trade control power increases, and China's trade control power decreases in this period. And the U.S. has been in the leading position in terms of its control over midstream nickel trade.

Overall, the diversity of trade in downstream nickel products has increased over the study period. Germany, the Netherlands and the United States have always occupied the top three positions in this indicator, probably because of their higher technological level and favorable geographical location. Compared with other countries, the diversification of China's import sources is more obvious, and in the study period, China's inward and outward values have increased, showing an increase in the diversification of China's import sources and export destinations, which, all things being equal, reflects that the status of China's nickel import trade has improved significantly, the risk of resource outages has been reduced, and the level of security of nickel trade has been improved.

Whether it is upstream nickel product trade or downstream nickel product trade, the trade influence of major nickel-producing countries is not prominent, on the contrary, the Netherlands, Germany and Spain in Europe, the United States and Canada in North America, as well as China and Singapore in Asia, the trade influence of these countries is more prominent. The reason for this is that countries committed to carbon emission reduction, the development of clean energy technology to promote new energy key metal demand increases, resulting in nickel resource demand countries trade influence gradually increased. This shows that the influence of global nickel-producing countries on the global trade of lithium products is much lower than that of nickel-demanding countries, and the future evolution of the global trade pattern of nickel products will undergo important changes with the birth of new technologies.

4. Conclusion

Looking at the network as a whole, the global trade network of copper and nickel resources across the industrial chain is characterized by increased complexity and connectivity. However, due to the relative concentration of the global distribution of resources in a few countries, the trade network shows the phenomenon of uneven distribution of nodes, with the characteristics of a small-world network. It is worth noting that, as cobalt ore is often produced as an associated ore, its output is often constrained by the carrier ore, and due to the resource countries' own prioritized development strategy, the complexity of the cobalt upstream trade network is significantly lower than that of copper and nickel, but it also shows an enhanced trend in the study period. At the same time, the trade network of copper, cobalt and nickel shows a trend of increasing dependence of countries.

In terms of the evolution of national status, China's role as a "bridge" in the global trade network of copper, cobalt and nickel has been highlighted, and its ability to connect with other countries has been maintained at a high level, becoming an important hub in the global trade network of copper, cobalt and nickel, with stronger trade control over other countries , and the overall network has become more flexible and free. flexible and free. The U.S. also shows strong control ability in the global trade network of copper, cobalt and nickel, in addition to which, the European countries represented by the Netherlands and the United Kingdom are also more prominent in the global trade of copper, cobalt and nickel. Moreover, the trade influence of resource-producing countries is significantly lower than that of resource-demanding countries, and the future evolution of the trade pattern may undergo important changes with the birth of new technologies in each demand country.

From the perspective of the whole industry chain of individual mineral species, China has shown strong consistency in the global trade of copper, with a stable ranking in the centrality index, and a stronger overall control of trade. For cobalt global trade, in the upstream China's entry degree and exit degree rankings continue to rise, and the entry degree rises faster, showing that China continues to strengthen the diversity of upstream resource sources; in the midstream, compared with the upstream exit degree rankings slightly backward, but the upstream and midstream trade control is basically the same, control ability is stronger. In the downstream cobalt trade, China's import sources are more diversified, but compared with the upstream and midstream, the degree of output is not ranked high and the control ability of the downstream products is poor. From the nickel ore global trade point of view, in the upstream into the degree of rise faster, out of the degree of ranking is more stable to remain in the forefront of the world, and in the upstream of the trade control is more powerful and stable; For the midstream link, into the degree of ranking ahead of the degree of ranking out of the degree of ranking of the upstream is a little weaker than the midstream for the midstream fluctuations in the ability to control the whole is not as good as the upper reaches. In the downstream link, the degree of import diversification is high, but the overall trade influence is not large, and the trade control ability for the downstream link is poor.

From the perspective of the whole industry chain, in the upstream link, the complexity of copper trade network is significantly higher than cobalt and nickel. Cobalt is mainly produced as a by-product, and its output will be constrained by the carrier metal, while the distribution of resources is more concentrated, which may be the main reason for the low complexity of cobalt upstream trade network. For nickel, the distribution of resources is highly concentrated, with Indonesia supplying nearly half of the world's nickel ore, but resource supply is tight due to policies such as export restrictions by resource countries, resulting in a less complex network. At the same time, from the degree of centrality indicators can be seen, countries are accelerating the layout of overseas resources, to enhance the degree of diversification of domestic resource imports, to protect the security of domestic resources. In the middle and downstream segments, copper, cobalt and nickel trade networks all show a higher degree of complexity, the degree of aggregation of the network has increased, the connectivity of the network is constantly optimized, and the agglomeration effect is gradually highlighted. European countries represented by the Netherlands occupy the core position in the network due to their technical level, geographical location and other advantages. China's core position in the middle and downstream trade of copper is prominent, thanks to China's resource endowment and other advantages. But in the downstream trade of cobalt and nickel, its trade control ability is relatively weaker than that of copper trade, which needs to be strengthened.

From a comprehensive point of view, in the global trade of copper, cobalt and nickel, China has been strengthening the diversity of import sources in various segments in order to seek the stability of the supply of overseas resources, but as a large consumer of copper, cobalt and nickel, China is obviously constrained by others in the downstream high-tech products. In order to realize China's transformation from a "resource power" to a "resource power", it is necessary to fully upgrade the level of science and technology, and continuously improve the trade status and share of downstream end-use products with high value-added and high-tech applications.

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