Oil is an important strategic resource of the country, and the oil trade structure is related to national oil security. In this paper, based on the data of China’s oil import trade from 2017 to 2021, using the methods of import concentration, the Shannon entropy index, and quantitative evaluation of trade structure, the authors analyze the import pattern and the trade structure security of 7 oil varieties, including crude oil, vehicle gasoline, aviation gasoline, naphtha, aviation kerosene, No. 5-7 fuel oil, unburned petroleum coke, and petroleum asphalt. The research shows that the trend of the large-scale and diversified import patterns of China’s oil import is obvious, and the main importing countries of various oil varieties are relatively stable. The structural security of crude oil is the highest, and the import structure is a medium and highly-centralized oligopoly. The import structure of other oil varieties belongs to a highly-centralized or very highly-centralized oligopoly. The security of the import structure of China’s oil varieties is low and shows a downward trend. As shown by the early warning calculations of the trade structure, increasing the number and transaction proportion of the trading partners in the collaborative growth zone and reducing the number and transaction proportion of the trading partners in reverse inhibition zone, we can optimize the oil varieties import structure of China.

**Keywords:** oil trade, pattern security, assessment, import.

1. Introduction

Oil is an important strategic resource of the country. Oil is related to national security, social economy, and sustainable development [1, 2]. Due to the uneven spatial distribution of the world oil resources and the dislocation of supply and demand under the differences in the resource endowment, the contradiction between oil supply and demand has existed for a long time [3], and the trade gap between oil supply and demand is increasing.

Since 1993, China’s oil imports have exceeded its exports, and China has become a net oil importer. In 2015, China's oil consumption was 578 million tons, accounting for 13.3% of the world's total oil consumption [4]. In 2016, China overtook the...
United States to become the world’s largest oil importer. In recent years, China’s domestic GDP has maintained a growth rate of about 6%, and the rapid economic growth has increased its dependence on oil demand. According to the data, the imported oil in 2020 is about 617 million tons [5]. At the same time, the growth rate of China’s oil production is as low as 2% [6]. The massive growth of China’s oil consumption demand and the limited domestic oil supply has strengthened China’s demand for oil imports, with an external import dependence of more than 70%, which is much higher than the warning line set by the International Energy Agency for crude oil import dependence [7].

The impact of the sharp rise and fall of oil prices on China’s economy is constantly superimposed. In early 2020, under the influence of COVID-19, the global economic blockade led to a sharp decline in oil consumption. OPEC and other major oil-exporting areas made measures to reduce production but failed to reverse the structural imbalance of international oil supply and demand, and international oil prices fell to a historical minimum. In 2021, the slow economic recovery of major economies has stimulated international oil consumption, superimposed the reduction of oil production in major oil-producing areas in 2020, and the short-term oil supply is lower than the actual demand, resulting in the continuous rise of international oil prices. At the same time, the domestic political and social unrest in oil supply, international oil embargoes, sanctions obstructing the key transmission channels, geopolitical tensions, and the destruction of oil production facilities by major natural disasters such as earthquakes, tsunamis, and hurricanes have caused fluctuations in international oil prices [3].

On the issue of oil trade security, academia has mainly researched the following aspects: first, from the aspects of oil transportation security, the oil transportation channels [8], ocean transportation [9,10], and transportation channel development [11,12], it has researched the security and pattern of oil import channels. Second, it has evaluated the oil price and exchange rate security, reducing the risk of oil price and exchange rate fluctuations by optimizing the portfolio investment strategies [13,14]. From a financial perspective, this research has made a series of progress by combining financial asset allocation, exchange rate settlement, and oil trade. Third, the research has been focused on how to evaluate the oil trade security. Qu et al. [15] established the oil security evaluation index system and analyzed the oil supply security. Lu et al. [16] proposed the oil security index to evaluate the resource security on the basis of resource supply security, economic payment security, geographical security, and transportation security and analyzed China’s oil trade security from the aspects of oil reserve production ratio, oil external dependence, and oil reserve level. Besides, the common oil security research methods include the oil vulnerability index [17], potential risk index [18], diversification index [19], etc. Summing up, the existing oil security research has made a series of achievements, but the relevant research mainly focuses on the analysis of the influencing factors of oil import risks. Oil transportation, oil price, exchange rate, and political risks of the supplier countries are the uncontrollable factors. How to reduce the oil security risks from national controllable factors is worth discussing.

In recent years, scholars began to explore the temporal and spatial security pattern of oil [1, 20]. Yan et al. [20] applied the spatial analysis method to describe the evolution characteristics of the temporal and spatial pattern of China’s crude oil import trade. Cheng et al. [3] described the spatial pattern of China’s oil import trade by analyzing the data of China’s oil import and export trade from 1993 to 2016. From the perspective of the resource flow, Liu et al. [1] quantitatively described the changing trend of China’s oil resource supply network and temporal and spatial pattern from 1993 to 2015 based on the complex network method. Existing studies provide new ideas for oil security analysis, but most of them analyze a single crude oil product and do not analyze the related costs of oil, aviation kerosene, fuel oil, and other related products. There is no literature to explore China’s oil trade security from the perspective of the import and export trade structure.

Therefore, based on the existing results, this paper proposes a method for structural safety assessment of oil import and export trade. Based on the China Customs data for 2017-2021 years, the Chinese mainland and oil trading partners deal with the 7 main trading entities, including petroleum, motor vehicle gasoline, aviation gasoline, naphtha, aviation kerosene, fuel 5-7, non-calcinable petroleum coke, and petroleum pitch. This paper comprehensively discusses the trade pattern and trade structure evolution of seven products in China in recent years, evaluates the comprehensive security level of the oil trade structure, and provides support for the national oil trade security strategy.
2. Research Methods

2.1. Import concentration

The import concentration is generally expressed by the proportion of the total import volume of the top countries or regions in the total import volume. $\tau_{ij}$ refers to China’s import volume of the $i$th oil variety in country $j$, and $\sum_{j=1}^{N} \tau_{ij}$ is the total import volume of the $i$th oil variety in China in a certain year. Then, the import concentration can be expressed as:

$$CR_p = \sum_{j=1}^{p} \frac{\tau_{ij}}{\sum_{j=1}^{N} \tau_{ij}}.$$  \hspace{1cm} (1)

When $p = 4$, the import concentration index means the proportion of the total import volume of the top four countries or regions in China’s oil import volume in the total import volume of the variety. Based on Bain’s classification of market structure types [3, 21], China’s oil import structure is divided into six types.

2.2. Shannon entropy index

In 1948, the Shannon entropy index was proposed by Shannon, the founder of the information theory, to measure the uncertainty and differences within the system. It is widely used internationally to measure the geospatial aggregation degree of import and export trade. The higher its value, the more scattered and uniform the distribution of trading partners and the less vulnerable it is to interference. Referring to the research of Liu [1], based on the Shannon entropy index, this paper constructs China’s $i$th oil variety import trade structure security measurement index $S_i$, and its calculation formula is as follows:

$$S_i = -\sum_{j=1}^{N} \ln \left( \frac{\tau_{ij}}{\sum_{j=1}^{N} \tau_{ij}} \right) \cdot \ln \left( \frac{\tau_{ij}}{\sum_{j=1}^{N} \tau_{ij}} \right).$$ \hspace{1cm} (2)

Where $\tau_{ij}$ is the import volume of the $i$th oil variety from China to country $j$, and $\sum_{j=1}^{N} \tau_{ij}$ is the total import volume of the $i$th oil variety from China in the current year. The greater the uncertainty of $\tau_{ij}/\sum_{j=1}^{N} \tau_{ij}$ and the greater the value of $S_i$, the higher the security of the $i$th oil variety trade network structure. On the contrary, the smaller the $S_i$ value, the lower the security degree of the $i$th oil variety trade network structure.

When

$$\frac{\tau_{i1}}{\sum_{j=1}^{N} \tau_{ij}} = \frac{\tau_{i2}}{\sum_{j=1}^{N} \tau_{ij}} = \cdots = \frac{\tau_{iN}}{\sum_{j=1}^{N} \tau_{ij}} = \frac{1}{N},$$

$S_i$ takes the maximum value $\ln N$. At this time, the transaction between China and oil variety trading partner countries reaches the best equilibrium state, and the security degree of the oil variety trade structure is the highest. Theoretically, the greater the $N$, the higher is the number of trading partners of China’s oil varieties, the higher the average total amount of oil imported by

| Level | Value range | Degree of concentration          |
|-------|-------------|----------------------------------|
| I     | $CR_i \geq 0.75$ | Extremely oligopolistic          |
| II    | $0.5 \leq CR_i < 0.65; 0.75 \leq CR_i < 0.85$ | Highly concentrated oligopoly    |
| III   | $0.5 \leq CR_i < 0.65; 0.75 \leq CR_i < 0.85$ | Middle-upper concentrated oligopoly|
| IV    | $0.3 \leq CR_i < 0.35; 0.4 \leq CR_i < 0.45$ | Middle and lower concentrated oligopoly |
| V     | $0.3 \leq CR_i < 0.35; 0.4 \leq CR_i < 0.45$ | Low concentration oligopoly      |
| VI    | $CR_i < 0.3; CR_i < 0.4$ | Competitiveness                 |
China to every country, and the higher the security of the oil variety trade structure. However, in fact, only a few countries in the world have large-scale export potential, and some imported products of China’s oil varieties are concentrated in a few countries.

### 2.3. Import homogeneity

Although the above formula can effectively evaluate the overall security of trade networks of different oil varieties, it cannot identify the impact of different trading partners on the security of trade structure. Therefore, this paper further analyzes the early warning of the security risks of the trade structure according to the import homogeneity of the \( i \)th oil variety in the \( j \)th country. The calculation formula of homogeneity of a single importing country is as follows:

\[
 f(x) = -x \ln x, \quad \tau_x = \sum_{j=1}^{N} \tau_j
\]

China has become the world’s largest oil importer. Therefore, this paper focuses on the security early warning analysis of the oil import trade. When \( \tau_x \) is the import volume, the homogeneity can be used for the security early warning analysis of import trade structure. For the \( i \)th oil variety, the sum of China’s import shares to all \( N \) countries is equal to 1, that is \( \sum_{j=1}^{N} x_j = 1 \). According to the function properties in Eq. (3), the function curve of \( f(x) \) presents an inverted “U” shape. When \( x = 1/e \), the highest import homogeneity of the \( i \)th oil in the \( j \)th country is \( 1/e \). When \( x \in (0,1/e) \), \( f(x) \) increases monotonically, that is, when China’s share of oil imports to other countries is in this range, it has a synergistic growth potential. When \( x \in (1/e,1) \), \( f(x) \) decreases monotonically, that is, when China’s import share of oil varieties to other countries is in this range, it has a reverse inhibition potential and needs to make safety early warning.

### 3. Data sources

In this paper, the import volume data of PetroChina crude oil, vehicle gasoline, aviation gasoline, naphtha, aviation kerosene, No. 5-7 fuel oil, unburned petroleum coke, and petroleum asphalt for the period from 2017 to 2021 are derived from the data of China Customs. The data for 2021 is the total import volume in the first three quarters (January to September) of that year. China’s total oil import (export) comes from China’s statistical yearbook. For example, in 2019, China’s oil import was 581.02 million tons, China’s oil production was 191.01 million tons, and China’s oil export was only 82.11 million tons. The “oil” data comes from China’s statistical yearbook, including crude oil and various products processed and refined from the crude oil, including gasoline, kerosene, diesel, fuel oil, lubricating oil, naphtha, petroleum asphalt, and other petroleum products. This paper mainly studies the pattern and structural security of China’s oil import. In order to make the results clear and concise, the trading partner countries that account for a small proportion of China’s oil imports will be screened out when visualizing the data.

### 4. Results Analysis

#### 4.1. Pattern of China’s oil import and export trade

China is a large oil consumer, with a large gap between oil production and demand and a high dependence on imports. According to the data of the China Statistical Yearbook, in 2014, China’s oil import volume was 361.8 million tons. In 2016, China became the largest oil importer in the world. In recent years, the oil import volume has increased year by year, and the dependence on foreign

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Table 2. Division of the Impact of a Single Trading Partner on the Security of Trade Structure

| Domain of \( X \) | Domain interval division of the value of \( X \) |
|------------------|----------------------------------|
| \( 0 < x < 1/e \) | \((0,1/e)\) |
| \( 1/e < x < 1 \) | \(1/e\) |
| \( 1/e < x < 1 \) | \((1/e,1)\) |
| \( x = 1 \) | \(0\) |
oil has increased year by year. In 2020, at the beginning of 2020, the impact of COVID-19 was on the rise. In the context of the sharp decline in oil prices and the expansion of oil refining capacity, China’s economy gradually recovered from COVID-19, and oil demand rebounded. In terms of the month-on-month growth rate of oil imports, the growth rate of oil imports slowed down. In 2020, the oil demand increased by about 7.4% compared with 2019, and the import volume in 2020 was 617.9 million tons. As shown in Fig. 1, red blocks represent oil imports, blue blocks represent oil production, and yellow blocks represent oil exports.

In recent years, the growth rate of China’s domestic crude oil production has been slow and even decreased, with an annual growth rate of only 0.84% [20]. In 2014, the domestic oil production was 21.143 million tons, the highest over the years. In 2018, the domestic oil production was 189.32 million tons, the lowest in the previous years. In 2020, China’s domestic oil production is estimated to be 194.92 million tons. China’s oil export increased slightly year by year. In 2014, the oil export volume was 42.14 million tons. The absolute value of the export volume showed an increasing trend, but the month-on-month growth rate decreased. Therefore, this paper focuses on the analysis of China’s oil import pattern and structural security.

4.2. Analysis on trade pattern of oil varieties

This paper analyzes the trade pattern evolution of trading partners of seven products, including petroleum crude oil, vehicle and aviation gasoline, naphtha, aviation kerosene, No. 5-7 fuel oil, calcined petroleum coke, and petroleum asphalt in the period from 2017 to 2021. In this paper, the data of 2021 is the total import volume of the first three quarters of the year (January to September).

1. Crude oil. According to the data released by the General Administration of Customs, in the past five years, China has had as many as 46 oil import trading partners. The trading countries of oil import trade include not only the petroleum exporting countries but also emerging oil-producing and exporting countries. OPEC countries are still the major oil-importing partners of China. All 13 OPEC member states have established sustained and stable oil and crude oil trade relations with China. Except for Iran and Venezuela in 2021 and Venezuela’s no-oil trade with China in 2020, other countries have maintained crude oil trade relations with China for five consecutive years. Among the OPEC member states, Saudi Arabia, Iraq, and Angola rank among the top three in terms of oil exports to China. Over the past five years, OPEC member countries have imported 52.12% of the total oil imports.

In recent years, the diversification strategy of China’s import trade has emerged [3], and the number of importing countries has increased from 19 in 1996 to 46. The geographical distribution of oil imports has gradually expanded from Asian countries such as Southeast Asia, Northeast Asia, and West Asia to countries and regions in Africa, America, Europe, and Oceania. In 2019, China imported 50500 million tons of crude oil, and in 2020, China imported 54100 million tons of crude oil, with a year-on-year increase of 7.3%, creating a record maximum. In 2020, the top ten sources of China’s crude oil imports are Saudi Arabia, Russia, Iraq, Brazil, Angola, Oman, the United Arab Emirates, Kuwait, the United States, and Norway. At present, China also carries out oil trade with emerging Asian and African oil-producing countries such as Azerbaijan, Chad, and Cameroon. Africa plays an increasingly prominent role in China’s oil import pattern, but they currently play just a supporting role [22].
2. Naphtha. Naphtha is one of the main oil imports in China. It is used to produce benzene, toluene, xylene, ethylene, propylene, and other products. The import of naphtha in China is characterized by large quantities, miscellaneous varieties, wide sources, and many importing countries. The import volume of naphtha has increased greatly in recent years. From 2017 to 2021, there were 28 countries or regions trading naphtha with China, and the top five import source countries were South Korea, Russia, Algeria, and the United Arab Emirates. From 2017 to the first three quarters of 2021, China’s imports of naphtha were 666.75, 744.53, 702.5, 783.96, and 579.71 million tons, respectively, which decreased slightly in 2021 compared with 2020.

3. Vehicle gasoline and aviation gasoline. Aviation gasoline is a major obstacle restricting the development of China’s aviation industry. Due to the complexity of the aviation gasoline refining process, high technical standards, and small profit space, the
domestic production and supply are relatively small. In 2017, the import volume of China’s automotive and aviation gasoline was 16.45 million tons, the import volume increased to 48.05 million tons in 2020, and the trade import volume in the first three quarters of 2021 was 33.24 million tons, with an obvious growth trend. China has 15 trading partners in vehicle gasoline and aviation gasoline. In 2017, the Russian Federation and Japan were the main trading countries of the product. After 2018, South Korea and Singapore became the main trading partners of the product. The trading volume of vehicle gasoline and aviation gasoline between France, Poland, Italy, and other European countries and China is small and lacks sustainability, accounting for a small proportion of the total import.

4. Aviation kerosene. Aviation kerosene is one of the varieties of refined oil. With the rapid development of China’s national economy and the increase in international and domestic exchanges and cooperation, China’s aviation industry has developed rapidly, driving the increase of aviation kerosene consumption year by year. Aviation kerosene import source countries include South Korea, Malaysia, Japan, Singapore, and other countries, of which South Korea accounts for the largest proportion of transactions. As aviation kerosene is an important means of balancing supply and demand in China’s domestic market, there is overcapacity in China, and there is a phenomenon of large imports and export. In 2018, China’s aviation kerosene import volume was 406.19 million tons, only 248.45 million tons in 2020. In the first three quarters of 2021, the import volume was 114.38 million tons, and the import volume of aviation kerosene decreased significantly.

5. NO. 5-7 fuel oil. In China, the consumption of No. 5-7 fuel oil is mainly concentrated in the fields of transportation, petroleum processing raw materials, chemical industry, building materials, power, and thermal production [23]. The number of China’s fuel oil trading countries reached 52, including Malaysia, Singapore, the United Arab Emirates, Japan, Russia, and other countries. In 2017-2021, China’s fuel oil imports first increased and then decreased. The import volumes in 2017-2020 were 1347.22, 1660.39, 1497.44, and 12518500 tons, respectively, and the import volume in the first three quarters of 2021 was 9971400 tons. With the introduction of a series of policies such as China’s national energy conservation and emission reduction, shutting down high energy-consuming and polluting enterprises, and eliminating backward production capacity, the demand for fuel oil in China’s industry and electricity will continue to be replaced by other low-cost and environmentally-friendly resources. It is expected that the consumption market of fuel oil may shrink.

6. Unburned petroleum coke. Unburned petroleum coke is a by-product of oil refining. According to the Customs data, China’s imports of unburned petroleum coke peaked in 2019, with an import volume of 357.62 million tons, with an increase of 37% over 2017. Affected by domestic demand, environmental protection policies, and other factors, the import volume in 2020 was 321.76 million tons. The United States is still the largest source of petroleum coke imports to China, and other petroleum coke import sources include Colombia, Russia, Romania, Kazakhstan, Indonesia, Chile, Argentina, Brazil, and other countries and regions.

7. Petroleum asphalt. From 2017 to 2021, the import volume of petroleum asphalt was 503.84, 460.24, 429.38, 475.91, and 259.27 million tons, respectively. South Korea and Singapore are the two major source countries of China’s petroleum asphalt import. Other import sources include Malaysia, Thailand, Iraq, Japan, UAE, and other countries and regions according to the quantity. In recent years, South Korea has ranked first in the import volume, accounting for more than half of the import volume. Its advantage of low transportation cost is unmatched by other countries. Petroleum asphalt is one of the important products of the oil refining industry. Its main application fields include road construction, airport construction, water conservancy construction, and waterproof materials.

4.3 Trade structure security assessment

The calculated values of $CR_4$, $CR_8$, and $S_i$ of China’s oil imports from 2017 to 2021 are shown in Table 3.

It can be seen, that the $CR_4$ and $CR_8$ values of China’s crude oil imports fluctuate, rise slightly as a whole, and are still in the region of high value. In 2018, the $CR_4$ and $CR_8$ of petroleum crude oil were 0.478 and 0.732, respectively, in the middle and lower-concentrated oligopoly type. From 2019 to 2021, the $CR_4$ of crude oil is greater than 0.5, and the $CR_8$ of crude oil is greater than 0.75 in 2020. The import structure belongs to the middle and upper-centralized oligopoly type, and the import security of crude oil is reduced.

In terms of the proportion of China’s top four crude oil imports, the proportion of China’s crude oil imports from Russia, Saudi Arabia, Angola, and Iraq in 2017 was 14.22%, 12.46%, 12.04%, and 8.79%, respectively. The proportion of oil imports
was relatively uniform, $CR_4$ reaching the lowest value of 0.475, and $CR_8$ is 0.731. According to Bain’s classification standard, $0.35 \leq CR_4 < 0.5$; $0.45 \leq CR_8 < 0.75$, and the pattern of oil and crude oil import in 2017 was in the middle and lower-centralized oligopoly type. In 2020, there will be 44 oil import sources, but the main imports will be concentrated in the top eight countries, so the value will reach 0.756. In 2020, the top four countries are still Saudi Arabia, Russia, Iraq, and Angola, and the proportion of imported oil is 15.42%, 15.70%, 11.11%, and 7.72%, respectively. China’s crude oil imports from Saudi Arabia and Iraq is increased, while the oil imports from Angola decreased. According to Bain’s classification standard, $0.5 \leq CR_4 < 0.65$; $0.75 \leq CR_8 < 0.85$, and the pattern of oil and crude oil import in 2020 is in the middle and upper-centralized oligopoly type. The data show that China’s crude oil import is greatly restrained by the exporting countries. Once the output of major sources decreases and the export is adjusted normally, it will have an important impact on China’s oil security.

From 2017 to 2021, the proportion of naphtha imports showed a downward trend. In 2017, the top four naphtha trading partners were South Korea (33.96%), Russia (21.85%), the United States (6.24%), and India (7.95%). The top four trading partner countries are South Korea (21.94%), Algeria (19.83%), Russia (13.36%), and Qatar (8.29%). South Korea is China’s largest naphtha importer in recent five years, but its import proportion is decreasing year by year, and its internal structure is more optimized. According to Bain’s classification standard, $0.65 \leq CR_4 < 0.75$; $CR_8 \geq 0.85$, and China’s naphtha import pattern is a highly-concentrated oligopoly.

The trade scope of No. 5-7 fuel oil is the most extensive, involving 52 countries or regions, but the transaction concentration is still very high. In recent five years, the top eight total transactions accounted for more than 90%. In 2017, China’s major importers of fuel oil were South Korea and Singapore, accounting for 17.28% and 49.44%, respectively. The top two trading volumes accounted for 66.72% and 0.724%, respectively. In 2020, Malaysia was the partner with the largest trading volumes, accounting for 52.33%, followed by Singapore, accounting for 14.12%. According to Bain’s classification standard, the import pattern of China’s No. 5-7 fuel oil has changed from highly-concentrated oligopoly to extremely high oligopoly, with reduced safety.

South Korea is the largest exporter of vehicle gasoline, aviation gasoline, and aviation kerosene. From 2018 to 2020, South Korea’s exports of vehicle gasoline and aviation gasoline to China accounted for more than 90%. From January to September 2021, its exports accounted for 69.3%. In terms of aviation kerosene varieties, South Korea is the largest exporter. From 2017 to 2021, China’s aviation kerosene imports from South Korea accounted for 79.74%, 84.95%, 90.77%, 68.12%, and 68.94% of the total imports, respectively. China’s import patterns of vehicle gasoline, aviation gasoline, and aviation kerosene are extremely oligopolistic.

The import concentration of unburned petroleum coke and petroleum asphalt is also very high. From 2017 to 2021, there were 24 trading countries of unburned petroleum coke, but the import volume was mainly concentrated in the United States and Colombia. China’s annual imports of unburned petroleum coke from the United States account for about 50% of the total imports. In 2019, the concentration of imports has improved. The top four importing countries are the United States (48.66%), Colombia (16.13%), Russia (7.59%), and Romania (6.92%). In the past five years, the top four countries in petroleum asphalt import have always been Singapore, Malaysia, South Korea, and Thailand, and the import pattern has remained stable. The proportion of imports from South Korea and Singapore has increased year by year, from 55.03% in 2017 to 85.13% in 2021. The import pattern of unburned petroleum coke and petroleum asphalt is extremely oligopolistic.

Table 3. Changes of Oil Variety Concentration in China from 2017 to 2021

| Year | 2017 | 2018 | 2019 | 2020 | 2021 |
|------|------|------|------|------|------|
| **Index** | **CR4** | **CR8** | **S** | **CR4** | **CR8** | **S** | **CR4** | **CR8** | **S** | **CR4** | **CR8** | **S** |
| Crude oil | 0.475 | 0.731 | 2.874 | 0.478 | 0.732 | 2.834 | 0.515 | 0.737 | 2.794 | 0.5 | 0.756 | 2.782 | 0.518 | 0.773 | 2.706 |
| Naphtha | 0.713 | 0.904 | 2.090 | 0.713 | 0.913 | 2.168 | 0.712 | 0.895 | 2.175 | 0.634 | 0.839 | 2.195 | 0.675 | 0.884 | 2.045 |
| Vehicle gasoline | 0.992 | 1 | 0.801 | 0.91 | 1 | 1.504 | 1 | 1 | 0.669 | 0.765 | 1 | 1.792 | 1 | 1 | 0.820 |
| Aviation kerosene | 0.989 | 1 | 0.675 | 0.986 | 1 | 0.601 | 0.991 | 1 | 0.417 | 0.919 | 1 | 1.155 | 0.973 | 1 | 1.019 |
| No. 5-7 fuel oil | 0.724 | 0.933 | 1.819 | 0.749 | 0.904 | 2.089 | 0.781 | 0.928 | 1.923 | 0.813 | 0.96 | 1.676 | 0.922 | 0.986 | 1.326 |
| Petroleum coke | 0.852 | 0.957 | 1.538 | 0.841 | 0.953 | 1.453 | 0.793 | 0.947 | 1.735 | 0.843 | 0.975 | 1.681 | 0.819 | 0.954 | 1.594 |
| Petroleum asphalt | 0.985 | 1 | 0.849 | 0.977 | 1 | 0.998 | 0.976 | 0.999 | 1.217 | 0.943 | 0.997 | 1.321 | 0.943 | 0.998 | 1.206 |
From the Shannon entropy index $S_i$, the Shannon entropy index of petroleum crude oil is the highest, and the Shannon entropy index in recent five years is higher than 2.7, indicating that the import structure is the safest among the seven oil varieties. The Shannon entropy index of aviation kerosene is the lowest. In 2017 and 2019, the Shannon entropy index was 0.675 and 0.417, respectively. The proportion of aviation kerosene imported from South Korea in 2019 was 90.77%, indicating that the imported structural safety degree is the lowest. In 2020, the Shannon entropy index of aviation fuel is 1.155, indicating that the safety degree of import structure has increased. The Shannon entropy index of No. 5-7 fuel oil first increased and then decreased, and showed a downward trend year by year after 2018. The Shannon entropy index was 2.089 in 2018 and 1.676 in 2020, indicating that the concentration of $CR_4$ is improved and the safety of import structure is reduced.

4.4. Trade structure optimization strategy

Using the early warning calculation method of trade structure, this paper puts forward the optimization strategy of China’s oil import structure. Taking 2020 as an example, China imported 15.42% of crude oil from Russia, 19.83% of naphtha from Algeria, 6.02% of vehicle gasoline and aviation gasoline from Vietnam, and 27.84% of petroleum asphalt from Singapore, all of which are located on the left side of the extreme point 1/e, belonging to a coordinated growth region. The proportion of aviation kerosene imported from South Korea is 68.12%, the proportion of No. 5-7 fuel oil imported from Malaysia is 52.33%, and the proportion of petroleum coke imported from the United States is 42.42%, all of which are located on the right side of the extreme point 1/e, and the excessive import share of a single country inhibits the safety of the import structure. The proportion of national oil imports in the reverse inhibition zone is inversely proportional to Shannon entropy, and the proportion of national oil imports in the synergistic growth zone is directly proportional to Shannon entropy. Through the comparison of different years, we can intuitively identify the increase or decrease of countries in the reverse inhibition zone and optimize the allocation of import shares of partner countries.

5. Conclusions and Prospects

Based on the data of import trade of different Chinese oil varieties in the past 2017-2021 years, the Chinese mainland and China’s oil trading partners as the main body, this paper makes a quantitative assessment of the import concentration, the Shannon entropy index, and the trade structure of 7 petroleum varieties, namely, crude oil, motor and aviation gasoline, naphtha, aviation kerosene, fuel 5-7, non-calcined petroleum coke, and petroleum pitch. This paper analyzes the import pattern of different oil varieties and the evolution of their trade structure and evaluates the security level of China’s oil trade structure. The specific research conclusions are as follows:

1. From 2017 to 2021, China had 46 crude oil import trading partners, accounting for about 50% of the top four importing
countries, and the Shannon entropy index remained above 2.7. However, the dependence of China’s crude oil imports on Russia and Saudi Arabia has increased, the proportion of oil imported from the two countries has increased year by year, the oil import security structure has increased from the middle and lower-centralized oligopoly type to the middle and upper-centralized oligopoly type, and the security of oil crude oil import structure has weakened. Nevertheless, among the seven oil varieties analyzed in this paper, the import structure of naphtha is relatively the safest. The number of importing countries of naphtha is 28. The proportion of naphtha imports ranking in the top four is lower than that of the crude oil varieties but better than the other five oil varieties. The export volume of the top eight countries with naphtha exports accounts for about 90%, which is a highly concentrated oligopoly import structure.

2. The trade scope of No. 5-7 fuel oil is the most extensive, involving 52 countries or regions, but the transaction concentration is high. In recent five years, the main importing countries of No. 5-7 fuel oil are South Korea and Singapore, accounting for more than 60% of the total, and the top eight countries in the trading volume account for more than 90%. From 2017 to 2021, the import pattern of China’s No. 5-7 fuel oil changed from highly concentrated oligopoly to extremely oligopoly. From the Shannon entropy index, the safety of fuel oil has gradually decreased in recent years.

3. South Korea is the largest exporter of vehicle gasoline, aviation gasoline, and aviation kerosene. From 2018 to 2021, the proportion of vehicle gasoline and aviation gasoline exported by South Korea to China remained at more than 30% every year. From January to September 2021, its export proportion reached 69.3%. In terms of aviation kerosene varieties, South Korea is the largest, with an annual import volume accounting for more than 68%. The import pattern of China’s vehicle gasoline, aviation gasoline, and aviation kerosene is extremely oligopolistic, and the import risk is high.

4. The main importers of unburned petroleum coke are the United States and Colombia. Each year, the unburned petroleum coke imported from the two countries accounts for about 50% of the total import volume. In recent five years, the top four importers of unburned petroleum coke have remained Singapore, Malaysia, South Korea, and Thailand, and the import pattern has remained stable. The main importing countries of petroleum asphalt are South Korea and Singapore, and the import proportion increases year by year. In 2021, the import volumes of the two countries accounted for 85.13%, and the import pattern is extremely oligopoly.

The research shows that the trend of large-scale and diversified import patterns of China’s oil import is obvious. China’s dependence on oil imports is high, the gap between supply and demand is large, and the structural security needs to be improved. Using the early warning calculation method of trade structure, increasing the number and the transaction proportion of trading partners in the synergistic growth zone and reducing the number and the transaction proportion of trading partners in the reverse inhibition zone can optimize China’s oil import structure.

The security of the import structure of oil varieties involves not only the stability of supply but also the rationality of oil resource price. Due to space constraints, this paper does not discuss the risks of China’s oil import caused by geopolitical factors, the supply risk caused by price factors, the impact of the epidemic on the economy, and the impact of oil transportation channels, climate change, and other factors on the pattern of oil import. The deficiency of the above research is also an important issue that needs further research in the future.

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